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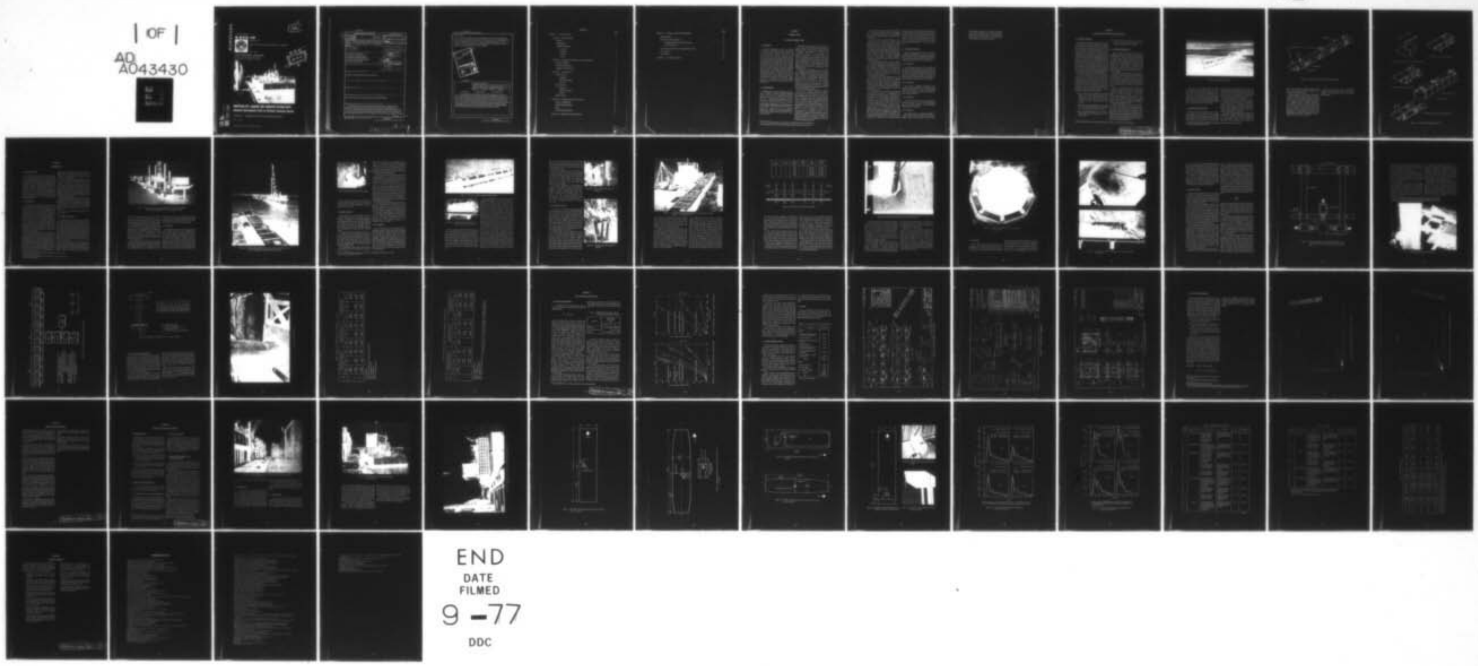

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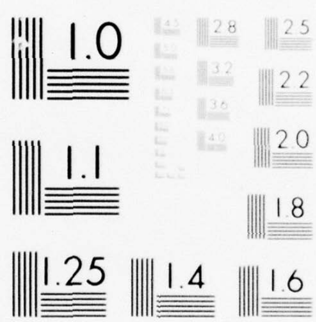

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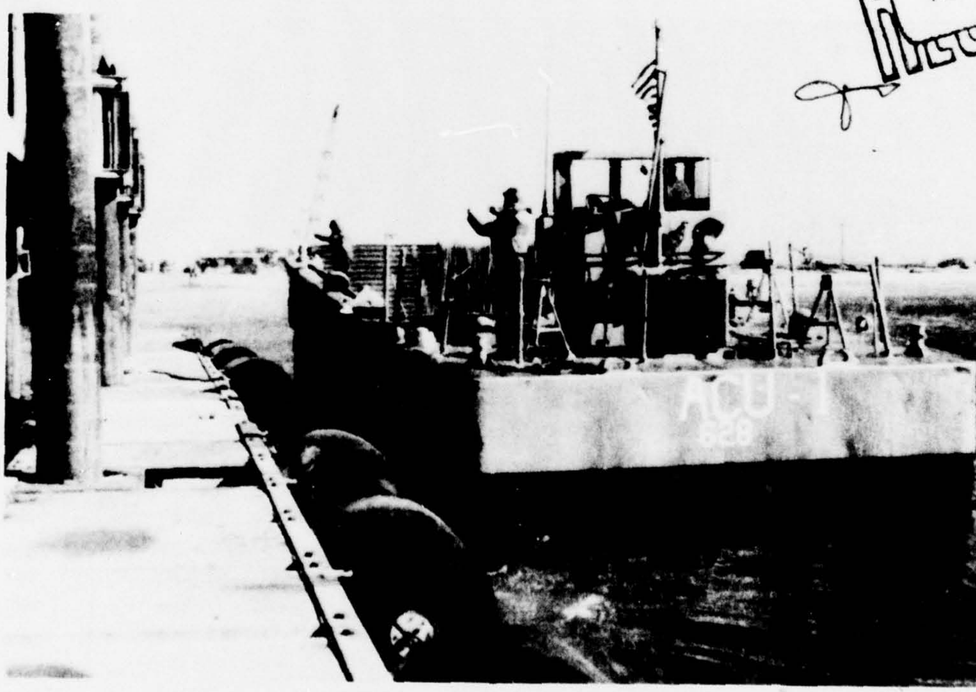

CONTAINER OFF-LOADING AND TRANSFER SYSTEM (COTS)

Advanced Development Tests of Elevated Causeway System

VOLUME IV – FENDER SYSTEM AND LIGHTERAGE MOTIONS

by D. A. Davis

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The design, fabrication, and testing of a boat fender, which is compatible with a transportable elevated causeway system for unloading container-bearing lighterage, are described. The pile-restrained, floating fender is comprised of a standard 1x15 string of Navy NL pontoons faced with commercially available foam-filled cushions. Each fender unit has an overall length of 90.0 feet (27.4 m), a breadth of 11.0 feet (3.4 m), and a depth of 5.0 feet

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1. Boat fenders 2. Lighter motions I. Y41X6-001-01-001

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CONTENTS

CHAPTER 1

FENDER SYSTEM

SECTION 1 INTRODUCTION

1.1.1 PURPOSE

Advanced development tests of the elevated causeway were performed to evaluate system hardware using an adequate number of pontoon sections, existing military lighters and trucks, and 8 x 8 x 20-foot (2.4 x 2.4 x 6-m) commercial containers. The equipment tested included four specially assembled NL pontoon pierhead sections with internal spudwells, five* existing pontoon sections equipped with external spudwells, two types of plastic foam fender systems, three types of Navy lighters, one type of Marine Corps tractor/trailer, a turntable, and two types of commercial container handlers. In addition, other selected hardware items were evaluated during the operation. Timing data were taken at all pertinent points of the operation; however, this information was considered to be secondary to determining any operational limitations, proper procedures, and problems requiring further development efforts.

1.1.2 BACKGROUND

DOD planning for the logistics support to sustain major contingency operations, including amphibious assault operations and Logistics-Over-the-Shore (LOTS) evolutions, relies extensively on the utilization of U. S. Flag commercial shipping. Since the mid-1960s commercial shipping has been steadily shifting towards containerships, Roll-On/Roll-Off/(RO/RO) ships, and bargeships (e.g., LASH, SEABEE). By 1985 as much as 85% of U. S. Flag sealift capacity may be in container-capable ships – mainly non-self-sustaining (NSS) container-ships. Such ships cannot operate without extensive port facilities.

Amphibious assault and/or LOTS operations are usually conducted over undeveloped beaches, and expeditious response times preclude conventional port development. The handling of containers in this environment presents a serious problem. This problem is addressed in the overall DOD Over-the-Shore Discharge of Cargo (OSDOC) efforts, which involve developments by the Army, Navy, and Marine Corps. Guiding policy is documented in the "DOD Project Master Plan for Surface Container-Supported Distribution System" and the OASD I&L system definition paper "Over-the-Shore Discharge of Cargo (OSDOC) System."

In response to the DOD Master Plan, Navy Operational Requirement (OR-YSL03) has been prepared for an integrated Container Off-Loading and Transfer System (COTS) for discharging container-capable ships in the absence of port facilities. The COTS Navy Development Concept (NDCP) No. YSL03 was promulgated July 1975, and the Navy Material Command was tasked with development. The Naval Facilities Engineering Command has been assigned Principal Development Activity (PDA) with the Naval Sea Systems Command assisting.**

The COTS advanced development program includes the ship unloading subsystem, the ship-to-shore subsystem, and common system elements. The ship onloading subsystem includes: (a) the development of Temporary Container Discharge Facilities (TCDF) employing merchant ships and/or barges with add-on cranes and support equipment to off-load non-self-sustaining containerships alongside; (b) the development of Crane on Deck (COD) techniques and equipment for direct placement of cranes on the decks of NSS containerships to render them self-sustaining in an expedient manner; (c) the development of equipment and techniques to off-load RO/RO ships offshore; and (d) the development of interface equipment and techniques to enable ship discharge by helicopters (either existing or projected in other development programs).

*Six sections were used originally, but one section was lost during the early part of the Phase II tests.

**NAVFAC Program Plan for Container Off-Loading and Transfer System (COTS) of April 1977.

The ship-to-shore subsystem includes the development of elevated causeways to allow cargo handling over the surfline and development of self-propelled causeways to transport cargo from ships to the shoreside interface.

The commonality subsystem includes: (a) the development of wave attenuating Tethered Float Breakwaters (TFB) to provide protection to COTS operating elements; (b) the development of special cranes and/or crane systems to compensate for container motion experienced during afloat handling; (c) the development of transportability interface items to enable transport of essential outsized COTS equipment on merchant ships – particularly bargeships; and (d) the development of system integration components, such as moorings, fendering, communications and services.

The Civil Engineering Laboratory (CEL), NCBC, Port Hueneme, California, was designated by the Naval Facilities Engineering Command (NAVFAC) as the responsible laboratory for the ship-to-shore subsystem. These five volumes cover only that portion of the ship-to-shore subsystem related to the elevated causeway components and associated container-handling operations.

CEL planned the elevated causeway tests in two phases. The first phase tests, which were conducted from 16 June to 16 July 1975 by CEL at an open beach site at Point Mugu, California, were designed to investigate operational and structural capabilities of the NL elevated causeway and to develop operational procedures. No container-handling tests were included in this phase.

The Phase II tests were designed to be conducted by the military operators, i.e., PHIBCB-ONE and ACU-ONE, Coronado, California, to determine operational limitations and any further development requirements. Container-handling operations were included in these tests. The landing site was located on Silver Strand Beach, Green Beach Two, at coordinates 32°30' 08" latitude, 117° 09' 25" longitude. A survey of the landing site showed a beach gradient of about 1:30, a 20-foot (6-m) water depth 600 feet (183 m) offshore at zero tide. The pier was elevated by PHIBCB-ONE beginning 12 November 1975 and finishing on 26 November 1975. The container-handling crane was positioned on the pierhead on 1 December 1975. Container-handling operations began on 2 December and were completed on 5 December 1975. The pier was left elevated until 5 January 1976 to check for piling settlement and to provide an opportunity for the pier to encounter rough seas, and it was then disassembled from 5 January to 10 January 1976. A 16-mm, color, sound movie has been prepared that covers the Phase II tests.

1.1.3 REPORT COVERAGE

The final documentation, which covers results of both Phase I and Phase II tests, consists of a summary report (Volume I) with environmental data observed during the tests and four separate technical volumes. The four technical volumes cover the following:

1.1.3.1 Volume II

The elevating mechanism or lift system and alternative lift procedures and associated equipments are covered. A human engineering study was made of both the elevated causeway system hardware and the associated operational procedures. This study was conducted by the Human Factors Technical Division, Naval Electronics Laboratory Center, San Diego.

1.1.3.2 Volume III

The pontoon equipment (including section assembly, internal and external spudwells), structural reinforcements required for the container-handling crane, side connectors, and results of structural behavior tests are described.

1.1.3.3 Volume IV

The fender system, installation procedures, and lighterage impact tests are covered. Lighterage motions recorded during the container-handling operations are also compiled.

1.1.3.4 Volume V

This volume details the container handling, i.e., container-transfer rates, container crane, containers, lighters, Marine Corps truck/trailers, pontoon deck

reinforcement, turntable, beach ramp and matting, and air bearing transporters. An alternate method of ship-to-shore container transfer, i.e., the load-on/roll-off cause ferry system (Lo/Ro), using a commercial top-lift loader was tested and is described.

SECTION 2

FENDER SYSTEM FOR ELEVATED CAUSEWAY

1.2.1 DESIGN CRITERIA

The elevated causeway is comprised of a number of 3x15 NL pontoon sections [21.0 feet (6.4 m) wide and 90.0 feet (27.4 m) long] which are end-linked and side-connected together and supported clear of the water surface by steel piles (see Figure 1-1). Individual 3x15 pontoon sections arrive at the shore site aboard Navy LSTs and LSDs or aboard commercial bargeships. They are unloaded, linked together at sea to form the desired causeway configuration, and then beached. Steel piles that are inserted through spudwells in each pontoon section are driven into the seafloor. After the end and side connections are disconnected, individual causeway sections are elevated into position by portable hydraulic jacks atop the piles. The end and side connections are re-established, the fender system is installed, and the elevated causeway is ready to function as a cargo unloading pier.

An essential subsystem of the COTS elevated causeway is the fender (see Figure 1-1). The purpose of the fender is to absorb the kinetic energy of the cargo lighters during berthing and to prevent contact between the lighters and the pier support piling. After a preliminary conceptual design study it was decided that the fender should be configured to capitalize on standardized Navy NL pontoon equipment and commercially available off-the-shelf hardware. General performance standards to be met included:

- Must absorb, without damage, the berthing kinetic energy of the largest expected class of lighterage. A fully loaded 1610 Class LCU impacting at a velocity normal to the fender of 2 knots (1.0 m/sec) was assumed for this purpose.
- Must have a pier stand-off distance* that would not impose reach limitations on the pier cargo crane – about 10 or 11 feet (3.0 to 3.4 m).
- Must rise and fall with the tide so that the fender berthing surface would remain at or near the sea surface.
- Must function in sea state 3 [5 to 6-foot (1.5 to 1.8-m)] waves and survive waves up to 10 feet (3.0 m) in height.

1.2.2 FENDER DESCRIPTION

Figure 1-2 depicts the main elements of the experimental fender system. Basically, each fender unit is comprised of a 1x15 NL pontoon string modified to include three internal spudwells. The 6-inch (15.2-cm) assembly angles, P1 series pontoons, end connections, and miscellaneous pontoon assembly hardware are all standard Navy stock items. The fender has a total weight of 48,000 pounds (21,770 kg) and dimensions of 90.0 feet (27.4 m) in length, 11.0 feet (3.4 m) in breadth, and 5.0 feet (1.5 m) in height.

The CEL-developed spudwells are of open frame construction with outside dimensions matching those of a standard P1 series pontoon. They can be easily bolted into place between the string assembly angles. The spudwells are equipped with a chafing ring which serves to reduce friction between the piles and the fender when the fender is subjected to wave-induced motion.

A series of foam-filled, commercial ship fenders are strung outboard of the pontoon string. These ship fenders – hereafter referred to as "foam-filled cushions" or, simply, as "cushions" – have a low-density, closed-cell elastic foam interior and are enclosed with a reinforced elastomer cover. A steel core runs the length of the cushions and is capped by flanges at each end. Eyes, attached to the end flanges, are provided for rigging the cushions.

Standard marine hardware, e.g., swivels, shackles, wire straps, and turnbuckles, are used to rig the cushions to the 1x15 pontoon string. In Figure 1-3, note the vertical straps at either end of a cushion. These straps insure that the cushions are supported at the proper elevation for even flotation of the fender unit. They also provide redundancy so that a failure anywhere in the primary, axial rigging will not result in loss of the entire cushion string.

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*The horizontal distance normal to the elevated pier from the pier edge to the near side of the moored lighter.

Figure 1-1. COTS elevated causeway.

Since there is an overlap of about 6 inches (15.2 cm) between the elevated causeway and the inboard edge of the fender, the possibility of contact exists if the causeway elevation is insufficient and/or if high wave action is present. Any impact loads are mitigated by the cylindrical, hard rubber "bumpers" that are installed on the inboard top fender assembly angle. Three bumpers are normally used per fender unit, one at each end and one in the middle.

1.2.3 ASSEMBLY AND RIGGING

The first step in the assembly process is to bolt the standard P1 series pontoons to the assembly angles (Figure 1-3).* Two end cans and ten standard cans are needed for each fender. The three remaining can spaces are to be occupied by the internal spudwells that bolt to the assembly angles in the same manner as the standard P1 pontoons; these positions are located three cans in from each end of the string and in the center. The spudwells are positioned such that the off-center spud opening is nearest the inboard (pier side) edge of the 1x15 string.

It should be noted that in this particular application of the NL pontoon system, it is not necessary to weld the AP7 plates to the end cans. The installation of grates between cans is optional. The top of the fender will not normally be subjected to foot traffic; however, tagline handlers have used the fender as a walkway during periods of calm seas.

Next, the vertical strap padeyes are welded to the top and bottom assembly angles. The 1x15 string can be rotated, as necessary, to facilitate welding. The two end padeyes, which serve to anchor the turnbuckles, are then welded to the end cans. This

*See "Pontoon Gear Handbook, Navy Lightered (NL) Equipment P-Series," NAVFAC P-401, Nov 1974 for details on pontoon hardware assembly.

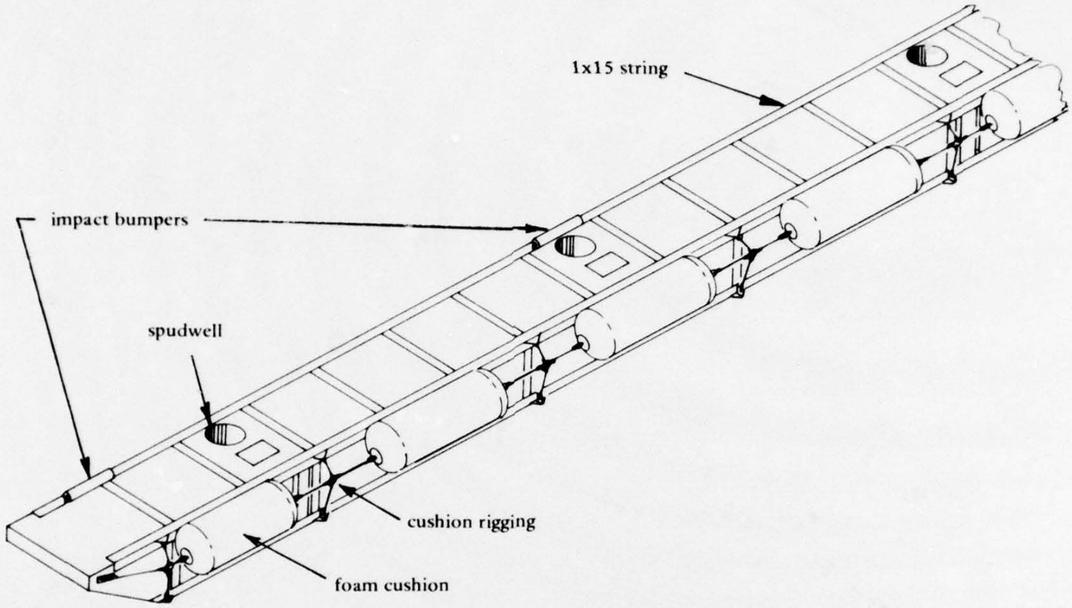
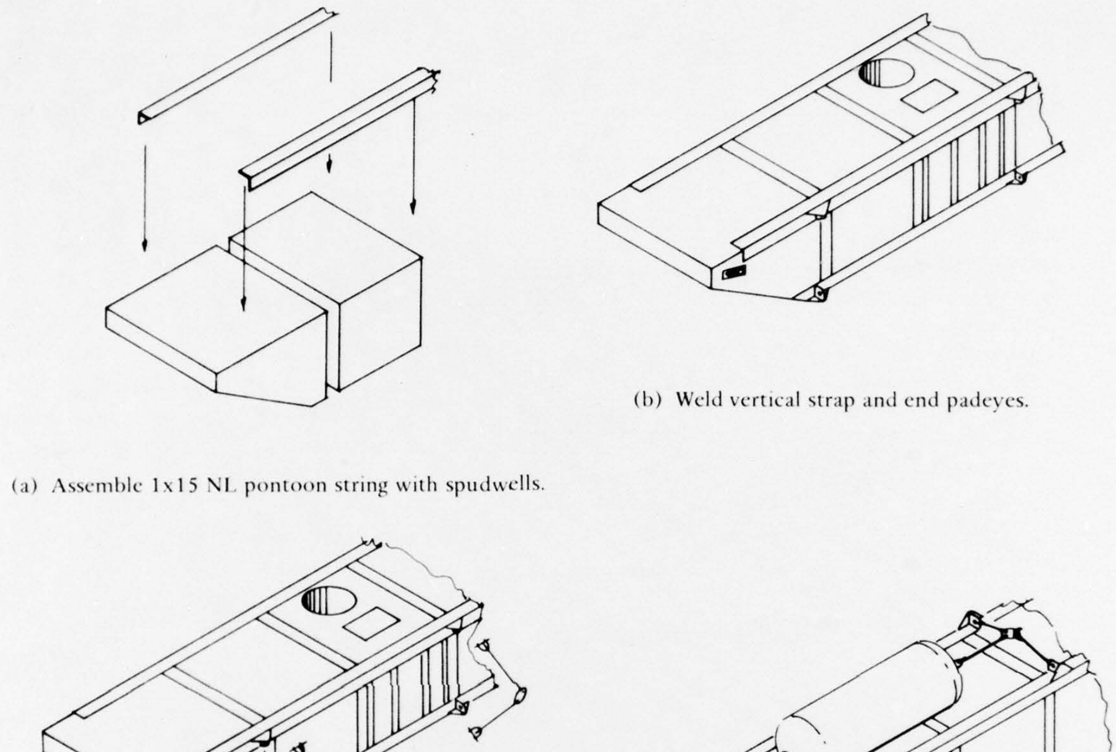


Figure 1-2. Fender system detail for COTS elevated causeway.

phase of the assembly is completed when the vertical wire rope top and bottom straps are shackled to the padeyes on the assembly angles.

Cushion rigging, the next phase of assembly, is simplified if the 1x15 string is first rotated so that the outboard face of the fender is upright. The cushions are then hoisted atop the string by forklift and placed at the appropriate position. Rigging commences as each foam-filled cushion is attached to the vertical and axial wire rope straps. Swivels are placed at each end of the cushions to insure free rotation, as this distributes cushion wear and lessens the chance for rigging failure. The turnbuckles at each end of the axial rigging are shackled to the end padeyes and are tightened to take up slack in the string.

Finally, the 1x15 fender unit is repositioned upright, and the retaining straps for the impact bumpers are welded in place on the top, inboard assembly angle.



(a) Assemble 1x15 NL pontoon string with spudwells.

(b) Weld vertical strap and end padeyes.

(c) Shackle vertical straps to padeyes.

(d) Rig cushions.

(e) Weld bumper straps to inboard assembly angle.

Figure 1-3. Fender assembly and rigging procedure.

SECTION 3

FENDER TESTS

1.3.1 PHASE I TESTS

The elevated pier for the Phase I tests at Point Mugu, California, consisted of four 3x15 NL causeway sections connected end-to-end, as illustrated in Figure 1-4.* One 1x15 NL fender unit was assembled, as outlined earlier, for installation alongside the seaward-most causeway section. The fender had four foam-filled cushions, nominally 4 feet (1.2 m) in diameter and 7.4 feet (2.3 m) in length, rigged to the outboard face of the 1x15 pontoon string (Figure 1-4). Three of these cushions were repaired Ocean Systems units that had been previously used on an Army dredging project, and one was a new Seaward International cushion.

1.3.1.1 Installation

After assembly at Port Hueneme, the fender was towed approximately 4 miles (6.4 km) to the test site (Figure 1-5), where it was installed alongside the elevated causeway. Four personnel were required for the warping tug operation: a pilot, one operator, and two line handlers. While the warping tug was preparing for its initial approach, the shore crew positioned a TD-25B tractor for use as a deadman for the bow wire of the tug. The pier crew, which was composed of a crane operator, an oiler, and two riggers, positioned a 50-foot (15.2-m) tipped pile into the center external spudwell on the elevated pier using a 35-ton (31,800-kg) mobile crane. The pile was held aloft to be inserted in the middle spudwell on the fender string, as shown in Figure 1-5.

A stern anchor was set from the warping tug, and a bow line was carried by a LARC-V to be secured to the beach tractor. The tug was able to position and hold itself parallel to the elevated causeway. Two unsuccessful attempts were made at inserting the pile in the middle spudwell on the 1x15; a third attempt was successful. The shoreward-most fender pile was lifted into position above the external spudwell. Incoming waves helped to position the 1x15. Again two unsuccessful attempts were made before the spudwell was stabbed. The warping tug then moved away. The third spudwell was pinned easily. At the time of installation, 2-to-4-foot (0.6-to-1.2-m) waves were observed at the causeway site.

The piles – 20-inch (50.8-cm) OD pipe, 50 feet (15.2 m) in length with a 3/8-inch (9.5-mm) wall thickness – were driven an estimated 5 feet (1.5 m) with a DE-30 diesel pile hammer. At least five people were required to conduct this operation. It was determined that this depth of penetration was inadequate; consequently, the piles were driven an additional 5 feet (1.5 m) the following day. Later, the shoreward-most pile was driven an additional 3 feet (0.9 m) before testing began.

After the fender piles were driven, the external spudwells were removed so that impact measurement instrumentation could be installed. Once the bolts were removed, the line from the 35-ton (31,800-kg) crane was hooked to the padeyes on the external spudwells, and the spudwells were raised with no binding.

From start to finish, the fender installation required 2 hours.

1.3.1.2 In-Place Performance

The fender system remained moored alongside the elevated causeway for 12 days. During the first day, the urethane covering on the flange plate of one of the Ocean Systems cushions began to wear away, and, on the following day, the foam slid off the pipe core (Figure 1-6). On the eighth day, the end of one of the repaired Ocean Systems cushions split open.** The excessive wearing of the foam-filled cushions was attributed to the fact that the fender system was exposed to the force of the breakers in the surf zone. Normally the fenders would be installed farther from shore, beyond the surf.

High waves, which occurred at times during the Phase I tests, and inadequate vertical clearance caused the fender system to collide with the underside of the elevated causeway. The greatest impact between the fender and the elevated pier occurred on the seaward

*Detailed description of the causeway elevation and pontoon equipment can be found in Volumes II, III, and V.

**These are prototype fenders that had been repaired at CEL. The current marketed product has been redesigned.

Figure 1-4. Elevated causeway system for Phase I. Note the four cylindrical foam-filled cushions rigged to the 1x15 NL pontoon fender.

end of the 1x15 fender string, 4 to 6 inches (10.2 to 15.2 cm) behind the assembly bolts. On the shoreward end, the damage was in the area of the last three pontoons and was restricted to bolthead wear on the assembly angle. The rubber impact bumpers on the seaward end of the fender system also received the most wear; the seaward-most bumper was abraded, and its restraining bar was deformed, which allowed steel-to-steel contact between the 1x15 and the elevated causeway. The boltheads on the underside of the causeway deformed the retaining bars on the other Seaward bumper. This bumper also shifted out of position.

The chafing rings, which served to prevent steel-to-steel contact between the fender piling and the edge of the spudwell, performed well. Several of the urethane pads, however, did separate from the steel backing plates. It was concluded that this problem was not due to any deficiency in the pads but, rather, to heat build-up during welding of the chafing rings that weakened the bond between the urethane elastomer and the steel backing plates.

1.3.1.3 Removal

Little difficulty was encountered in removing the fender system. The same crew and equipment that were used for installation were also used for removal. The removal operation was essentially a reversal of the installation procedure. The fender piles were removed in the following sequence: shoreward, middle, and seaward. The only incident of note during the fender removal occurred when the last pile was freed from the seafloor. Several large waves [height in excess of 8 feet (2.4 m)] caught the fender string. The pile, which was still restrained by the

Figure 1-5. Fender unit approaching elevated pier. Note 50-foot (15.2-m) piles ready for dropping into center spudwell of fender unit.

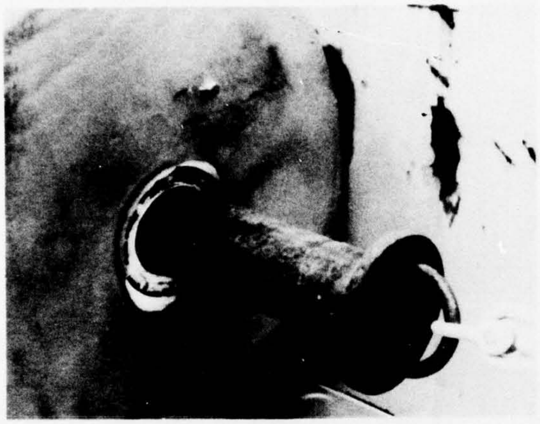


Figure 1-6. Pipe core pull-out on foam cushion.

internal spudwell, was pulled away from the pier, taking the attached crane line with it. The force in the crane line was of sufficient magnitude to raise the support pads of the crane.

1.3.2 PHASE II TESTS*

The objective of the COTS Phase II tests at Coronado, California, was to construct an elevated causeway of sufficient size that would demonstrate the operational feasibility of the concept. Unlike the four-section pier that was erected at Point Mugu by CEL support personnel, the Coronado pier was assembled by forces from the Amphibious Construction Battalion-ONE, assisted by CEL technical advisers.

The Coronado elevated causeway (Figure 1-1) was comprised of nine 3x15 NL pontoon causeway sections. Four sections were aligned two abreast to form a pierhead at the seaward end of the causeway. The fender system, consisting of two 1x15 strings instead of the single unit used during the Phase I tests, was installed alongside the south-facing edge of the pierhead (Figure 1-7).

The seaward-most fender was the unit used earlier in the Phase I tests. For the Coronado tests, the three Ocean Systems cushions were discarded, and the fender was re-rigged with six Seaward International cushions, 4 feet (1.2 m) in diameter with a length of 7.4 feet (2.3 m). Additional modifications made to this fender included stronger top impact bumpers and the welding of cushion reaction struts across the outboard face of the fender spudwells.

A second 1x15 NL pontoon fender was assembled at Port Hueneme for use in the Phase II tests. This fender differed from the original prototype primarily in the selection of foam-filled cushions. Three of the cushions were new Ocean Systems products – 4 feet (1.2 m) in diameter by 10 feet (3.0 m) in length – and one was an experimental cushion manufactured by Seaward International (Figure 1-8). This new Seaward cushion, measuring 4 feet (1.2 m) in diameter with a 7-foot (2.1-m) length, differs from the standard unit in that the rigid, solid core has been replaced by a wire rope net which envelops the exterior of the cushion. The intention of the design is to allow longitudinal compression and extension without risk of failing a rigid steel core.

Hard, elastomer spudwell chafing plates were not used in constructing the second fender due to late delivery of material at CEL. Oak 2 x 8-inch boards were substituted for the elastomer plates and were also used to replace damaged and missing elastomer on the spudwell chafing rings of the original fender.

After assembly and rigging, the two fender sections were launched at Port Hueneme, and, along with the four causeway pierhead sections, were loaded aboard a Navy LSD for transport to the Amphibious Base at Coronado.

1.3.2.1 Installation

The two fender units were end-connected at the Amphibious Base to form a fender system having a total berthing length of 180 feet (54.9 m). Standard NL pontoon end connectors were used. On 24 November 1975, the fender assembly was moored alongside a PHIBCB-ONE warping tug for the trip from San Diego Bay to the elevated causeway site on Silver Strand Beach. No serious handling problems were encountered, although the tug crew did comment on the lack of mooring bitts on the fender. Synthetic lines from the tug were secured to the fender assembly angles.

*CEL Movie FA/LDH 604, 16 mm, sound, color, 8 minutes, "COTS Elevated Causeway System – Fender System," Coronado, California, Nov. 1975.

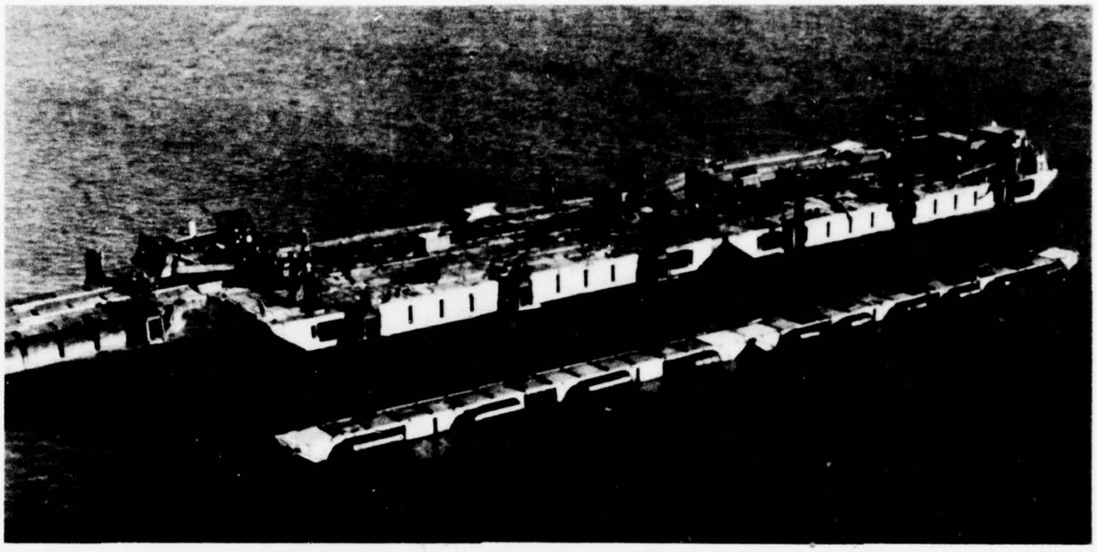


Figure 1-7. Two-section fender installed alongside pierhead.

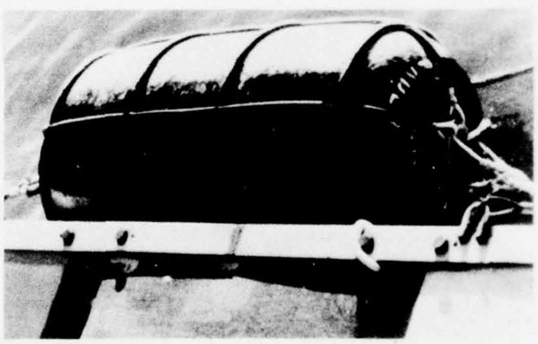


Figure 1-8. Experimental Seaward International cushion with exterior wire rope net.

Prior to the tug making its final approach at the elevated causeway site, a pier deck crew had inserted one of the tipped fender piles into the middle, external spudwell on the south-facing, shoreward-most pierhead causeway section (Figure 1-9). Their instructions were to drop the first pile when the fender system was properly aligned alongside the elevated causeway. Pile guides, i.e., steel sleeves, that fit inside the spudwell and are bolted to the spudwell's padeyes were used on five of the six fender piles (Figure 1-10).

The tug approached the pier at 1350, Pacific Standard Time (Figure 1-11). At the time winds were westerly at 8 to 9 knots (4.1 to 4.6 m/sec), and a 3-to-4-foot (0.9-to-1.2-m) swell was present as was a north-to-south, 1-to-2-knot (0.5-to-1.0-m/sec) alongshore current. Unlike the installation at Point Mugu, the tug did not depend on either a pre-set stern anchor or a bow line dead-ended at the beach for final positioning of the fender system. The first three approaches were unsuccessful and can be attributed to caution by the tug pilot and the persistent alongshore current which tended to force the tug and fender away from the elevated pier. On the fourth approach, lines were passed by the crew atop the pier to line handlers on the tug who secured the lines to the fore and aft ends of the fender. The tug continued to move the fender closer to the elevated pier, and, when the middle spudwell on the shoreward-most fender section was beneath the raised pile, a signal was given to drop the pile. With one pile in place, the two-unit fender assembly was easy to maneuver for the placement of the second pile, which was dropped into the middle spudwell on the seaward fender. At this point the tug cast off and returned to port. The four remaining piles were then placed, and operations for the day were terminated. The pile lengths were 55 feet (16.8 m) for the four closest to

shore and 60 feet (18.3 m) for the two most seaward ones. It had taken approximately 2 hours from the time that the tug had made its final approach to the elevated pier until the last of the six fender piles had been dropped into place.

Pile driving commenced on the morning of November 25 and proceeded without incident. Prior to driving the piling, it was noted that no discernible movement of the undriven piles had occurred from wave action or currents. Figure 1-12 summarizes pertinent data relating to the pile placement sequence, time of insertion, use of pile guides, and depth of pile embedment.

The external spudwells on the seaward-most pierhead causeway section were removed to allow installation of load arms and load cells that were needed to measure berthing impact loads. These impact measurements are discussed later in the report. The three external spudwells on the shoreward-most pier section were retained. Gussets were welded to the piles and spudwells so that the fender piles could support a portion of the pierhead crane load.

1.3.2.2 In-Place Performance

The fender was successfully demonstrated during the elevated causeway tests at Coronado. Berthing impacts for the three classes of lighterage (LCM-8, LCU, and causeway ferry) were light throughout the tests, well within the energy absorption capacity of the fender. The light berthing impact was due to a combination of factors: lighter crew skill and caution when approaching the "experimental" pier, an alongshore current that tended to keep craft away from the fender during and after berthing, and mild sea conditions throughout the week of 5 December when unloading operations were conducted.

No single cushion was ever observed to be compressed to its design limit (50% compression) during any of the container lighter berthings. A typical berthing could be described as follows: the lighter approaches the pier on a course roughly parallel to the fender. Forward speed is reduced, and the distance at right angles to fender and side of the lighter is reduced at a rate of about 1 fps (0.3 m/sec), or less. Bow and stern lines are passed from the lighter to the elevated pier line-handling crew and are wrapped

Figure 1-9. Deck crew prepared to drop first fender pile.

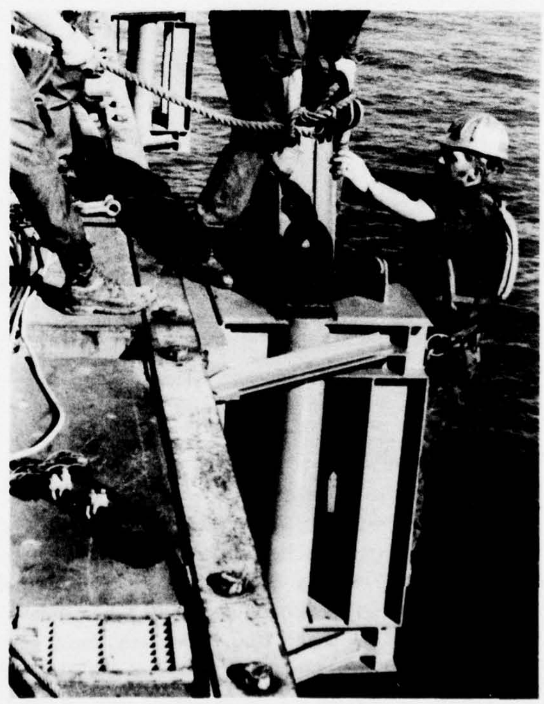


Figure 1-10. Installing pile guide in external spudwell.

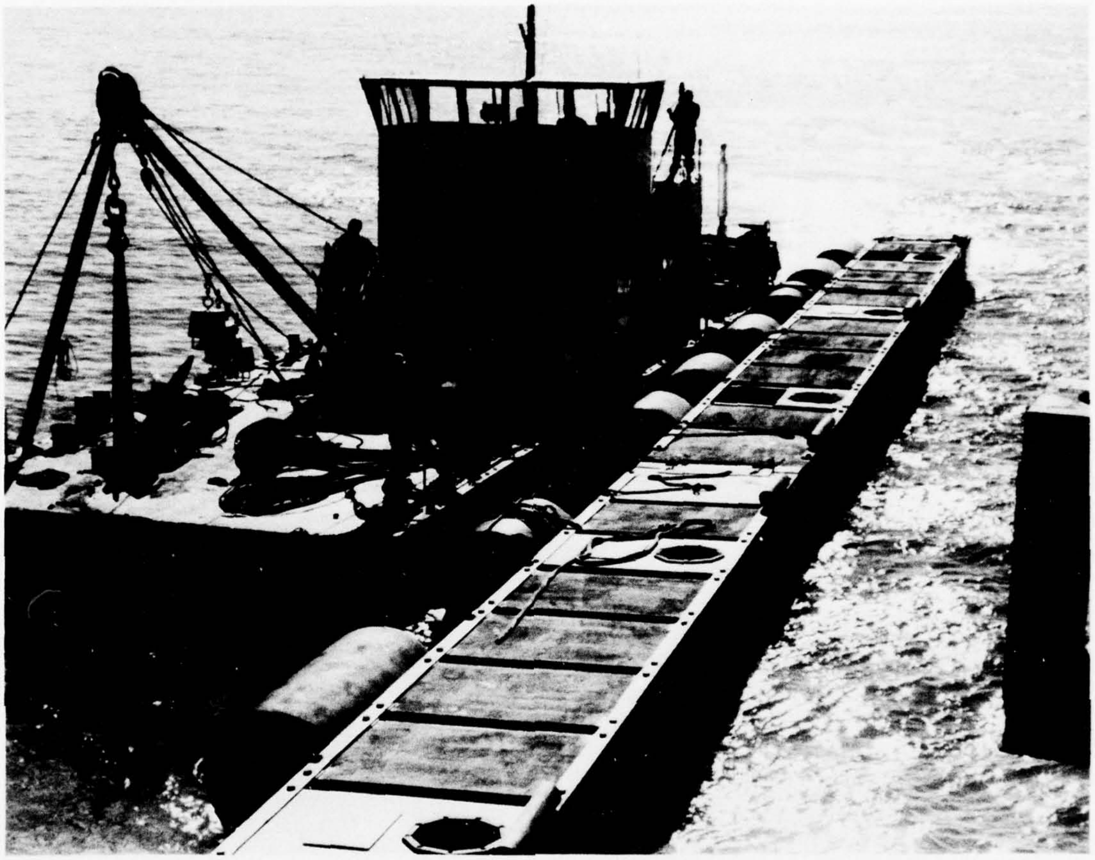


Figure 1-11. PHIBCB-ONE warping tug with fender in tow approaches elevated causeway – 24 November 1975.

around bitts on the pierhead just prior to lighter contact with the fender. After the lighter impacts with the fender, the lines are taken up further and secured to the bitts. While moored to the pier, the lighters would tend to ride away slightly from the fender due to the south-flowing current.

A principal concern prior to both the Phase I and Coronado tests was the possibility of fender warpage on the restraint piles. If this had occurred, the wave-induced hydrostatic and hydrodynamic forces could have easily caused damage to the piles, damage to the fender system, or might have led to freeing the piles from the seafloor. During both tests, however, the fender rode freely on the restraint piles, even during periods of high waves. It can be concluded, therefore, that the existing spudwell and chafing ring design is adequate to prevent warpage.

As mentioned earlier, two types of abrasion-resistant material were used to face the spudwell chafing rings. One was a hard elastomer, manufactured by Johnson Rubber Company, that had been used successfully during the Phase I tests, and the other material was oak planking. The elastomer proved to have far superior wearing properties than the wood. Within a week after installation of the fender, the wood chafing blocks were well worn, as evidenced by Figure 1-13. By this time some of the recessed carriage bolts, which were used to secure the oak to the steel backing plates, were in direct contact with the piles. As wearing continued, the exposed bolts were eroded away, and the piles were subjected to scoring, which, however, did not seriously damage the piles. Figure 1-14, which shows one of the spudwells on the shoreward-most fender section, shows

Pile Designation	Order of Placement	Time of Placement (PST)	Number of Pile Guides	Pile Length (ft, m)	Depth of Embedment (ft, m)
A	3	1525	1	60 (18.3)	11.6 (3.5)
B	2	1445	0	60 (18.3)	12.6 (3.8)
C	4	1535	1	55 (16.8)	12.8 (3.9)
D	6	1610	2	55 (16.8)	14.9 (4.5)
E	1	1415	2	55 (16.8)	19.3 (5.9)
F	5	1552	1	55 (16.8)	20.8 (6.3)

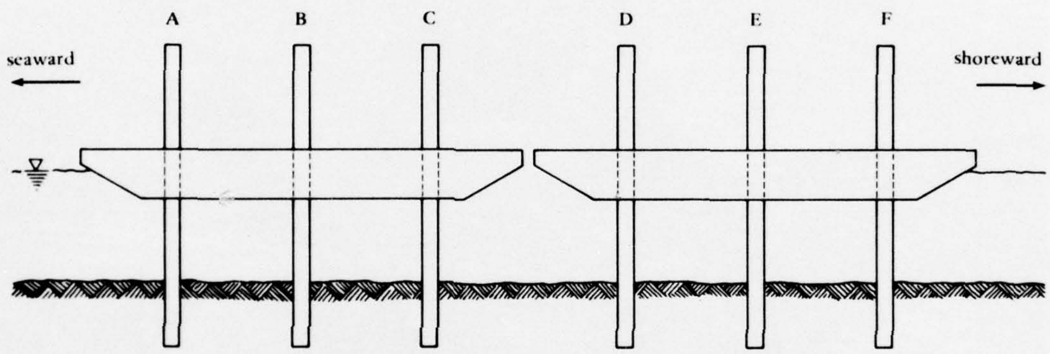


Figure 1-12. Summary of pertinent fender pile data.

the extent of wear after completion of the Coronado tests. Note that the oak block used to replace an elastomer block lost during the Phase I tests has been almost completely eroded away due to contact with the pile. The elastomer blocks show relatively little wear, although one block is missing due to failure of the bond between the elastomer and the steel backing plate.

Both the Seaward International and Ocean Systems foam-filled cushions performed satisfactorily. Core pull-out of the Ocean Systems cushions, which had occurred during the Phase I tests, was not repeated at Coronado. This was due to improvements in the cushion design and the absence of breaking waves that were encountered during the Phase I tests.

Shortly after installation of the fender system, a 4-to-5-inch (10.2-to-12.7-cm) long crack was noticed in the elastomer skin of one of the Seaward cushions (Figure 1-15). At the time of fender retrieval, the crack had propagated to a length of 9 inches (22.9 cm). It could not be determined when the initial failure had occurred, i.e., during cushion shipment to CEL, fender assembly, transport of the fender to Coronado, or installation of the fender at the elevated pier. The crack, however, can be easily repaired.

After the 1x15 fender sections were returned to CEL by Navy LSD, two of the 10-foot (3.0-m) long Ocean Systems cushions were also observed to have failures in the elastomer skin. This damage was thought to have taken place when the fenders were unloaded from the LSD at Port Hueneme, California.

Only minor problems were encountered with the cushion rigging. One of the vertical strap end links failed due to a poor weld between the end link and the 6-inch (15.2-cm) assembly angle. The redundancy of the rigging, however, prevented the loss of any portion of the cushion string.

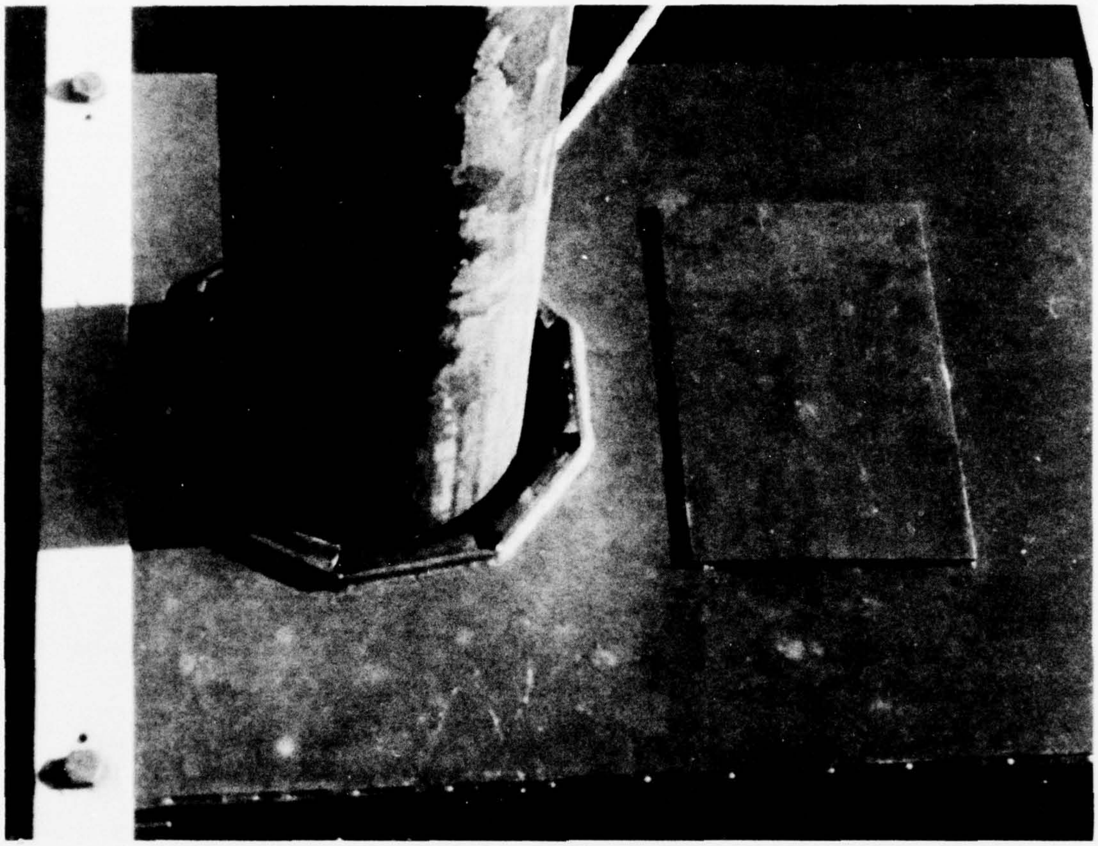


Figure 1-13. Wearing of oak chafing blocks after 1 week of service.

The experimental Seaward cushion was outfitted with an exterior wire rope net that was held together at each end of the cushion by a shackle. These shackles were in turn connected to the cushion axial rigging. After a while, wave-induced loads tended to stretch the wire net, which resulted in increasing the slack in the rigging. With only one cushion of that type of construction in the string, the slack was not too objectionable. Excessive slackening of the rigging is to be avoided, however, as this will lead to excessive wearing of the rigging components.

Perhaps the greatest weakness in the design of the fender is the inability of the cushion string to take sizeable longitudinal loads. Such loading could happen, for instance, if a lighter approached the fender with a significant forward velocity component and struck the 1x15 fender between cushions with the bow. The craft would continue to surge forward and would hit the next cushion; this could either fail the axial rigging or cause separation of the cushion's outer skin from the foam interior.

During one of the berthings, an LCU first impacted the Seaward International "experimental" cushion (on the shoreward-most 1x15 string), moved shoreward into the gap between cushions, and then longitudinally compressed the next cushion in the string, which happened to be one of the Ocean Systems units. As can be seen in Figure 1-16, the skin at one end of this cushion is abraded and severely scuffed, but the cushion was otherwise undamaged and continued to function normally. This problem can be minimized in the future by reducing the gap between adjacent cushions.

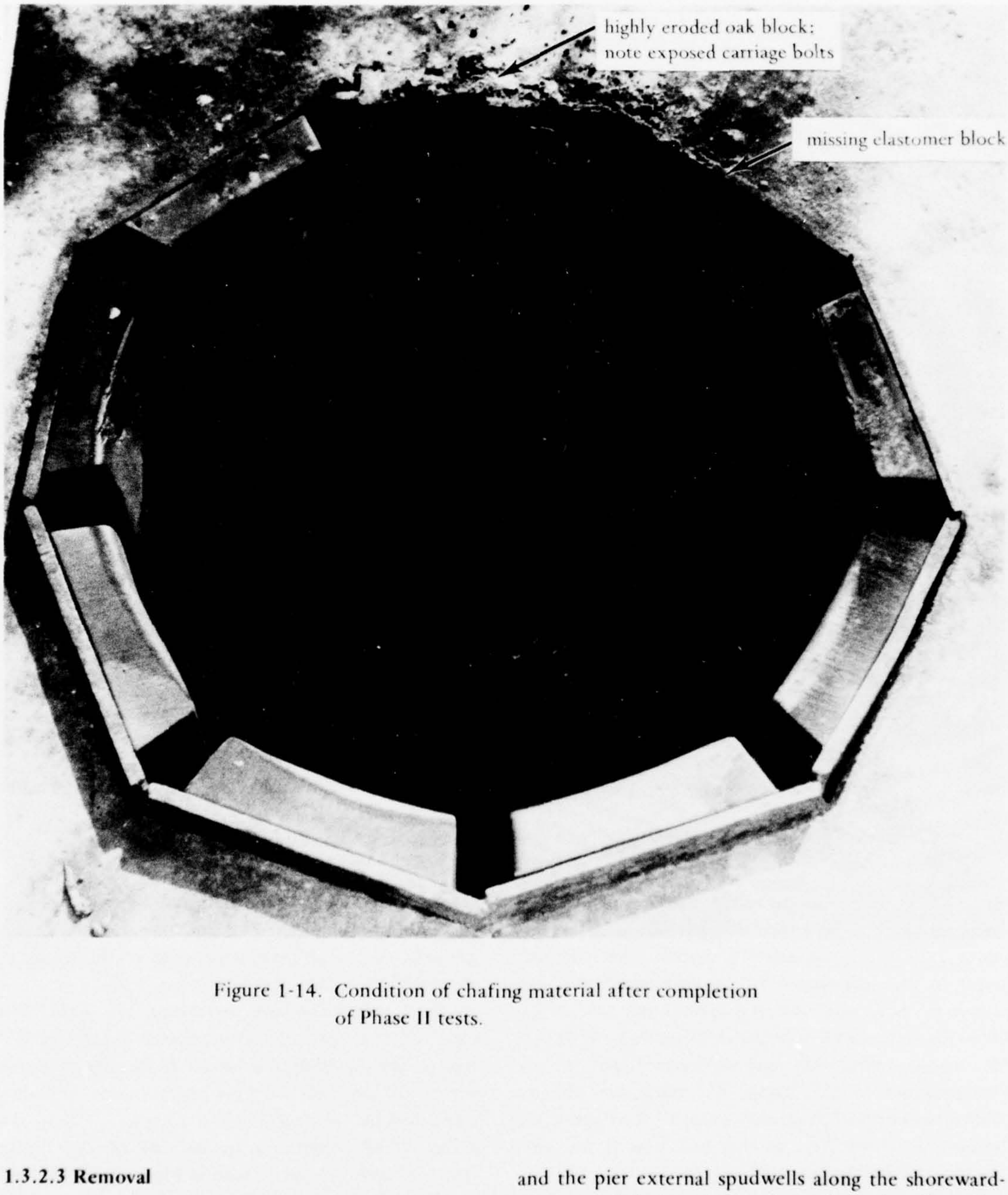


Figure 1-14. Condition of chafing material after completion of Phase II tests.

1.3.2.3 Removal

The fender system was the first piece of equipment to be removed upon completion of the elevated pier tests. The first step was to cut the gusset plates that had been welded between the fender piles and the pier external spudwells along the shoreward-most, south-facing pier section. Then, the pile guides were removed. Next, four of the fender piles were removed using the 35-ton (31,800-kg) crane atop the causeway. The two remaining piles which were located in the center spudwells of each fender

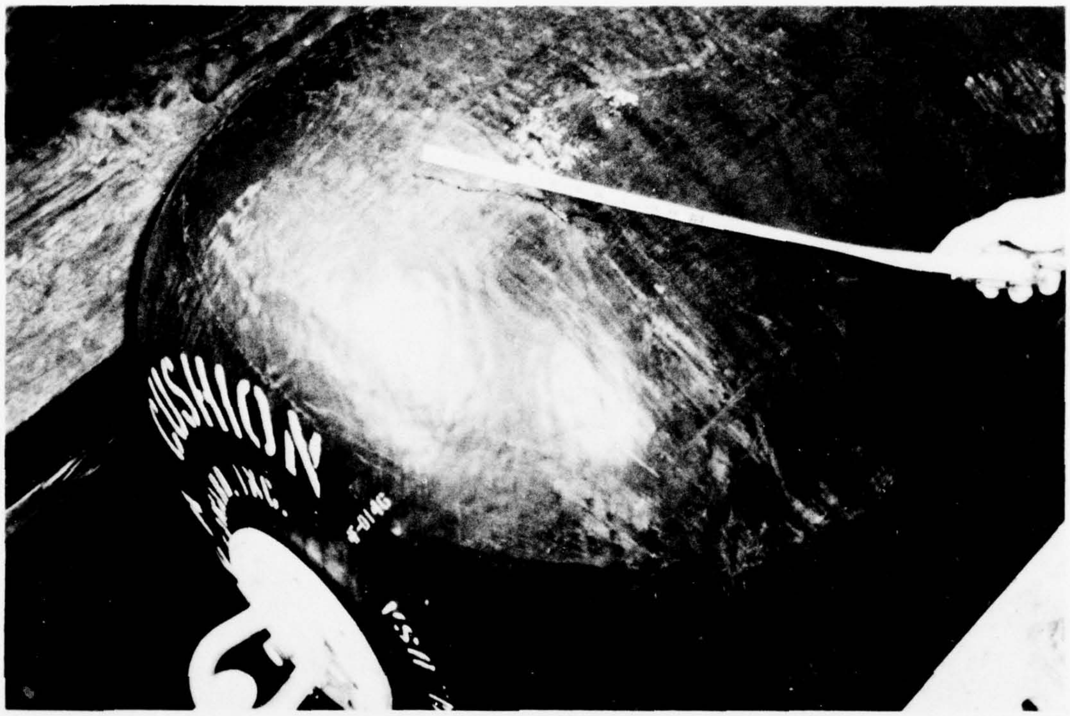


Figure 1-15. Crack in elastomer skin of Seaward International cushion.

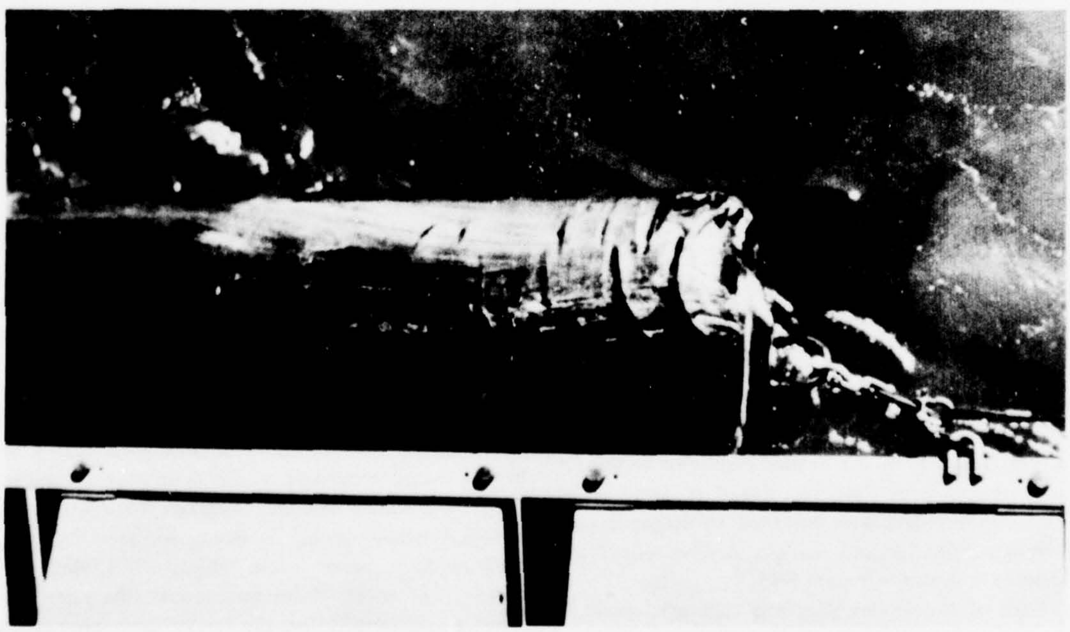


Figure 1-16. Abrasion on end of Ocean Systems cushion due to longitudinal compression.

section, stayed in place until a PHIBCB-ONE warping tug came alongside and tied on to the fender. The seaward pile was then pulled and, finally, the shoreward pile. The warping tug moved the fender system away from the elevated pier and returned with the fender in tow to the Amphibious Base at Coronado.

No difficulty was encountered in retrieving the fender. The piles were easily removed, and the tug and causeway line-handling crews were in control throughout. Sea conditions were mild, however, and undoutedly were a major contributing factor to the ease with which the operation was conducted.

1.3.3 IMPACT TESTS

Fender impact measurements were made during both Phase I and Phase II. The objective of the impact tests was to obtain data that could be used to evaluate the expected fender pile reaction loads at the elevated pierhead and to assess the energy-absorbing properties of the fender systems.

This objective was accomplished as follows: load cell supports, called load arms, were welded to the pierhead assembly angles, as illustrated in Figure 1-17. The load arms are essentially simple closed box girders that are sized to resist the anticipated loads and moments imposed by berthing lighters. Each of the three instrumented fender piles was bracketed by three load arms with the attached load cells bearing directly on the pile. With the arrangement depicted in Figures 1-17 and 1-18, it was possible to measure pile reactions both normal and parallel to the pier.

At each pile location, a linear displacement potentiometer was mounted to the side of the fixed pier. The end of the spring-loaded potentiometer cord was equipped with a permanent magnet which was lowered until it made contact with the top of the fender. Thus, vertical displacement of the fender (referenced to the pier) due to tidal and wave action could be recorded continuously. The velocity of the test craft normal to the fender just prior to impact was measured by a CMI, Inc. model JF 100 "Speed Gun." All test data were recorded on magnetic tape for future reduction and analysis. A schematic of the test setup is shown in Figure 1-19.

Each of the fender piles was calibrated prior to recording impact data. The purpose of this calibration was to determine the point of pile fixation in the seafloor. If both the fixation point and the position of the fender at the time of impact are known, it is possible to estimate the force in the piling at a station adjacent to the floating fender. The calibration procedure consisted of attaching a wire rope sling about each pile at deck level and pulling on the pile with a known force. Pulls were made in a horizontal plane with the line of action parallel to the edge of the elevated pier. A load cell and a line potentiometer were used to measure calibration force and pile deflection, respectively. The effective length of the pile (the length from the point where the calibration force is applied to the point of pile fixity) was computed from the following formula for the end deflection of a cantilever beam with a concentrated load at the free end:

$$\delta = \frac{R \ell^3}{3EI}$$

where δ is the end deflection (measured by the potentiometer in the pile calibration test), R is the calibration force, E is the modulus of elasticity, and I is the moment of inertia of the 20-inch (50.8-cm) diameter, 3/8-inch (0.95-cm) thick steel piling. Results of the pile calibration for the Phase II tests are given in Figure 1-20.

CEL's 268-ton (242,800-kg) warping tug was used to impact the fender during the Phase I tests. At the time of the tests, the single section 1x15 fender was in the surf zone. Consequently, the tug pilot approached the fender cautiously, relying largely on anchored stern line for control. About 10 impacts against the fender were made. This test series proved that the experimental setup would work; however, because of the unrealistic test conditions, these data are not discussed here.

The more important test series was conducted during the Phase II elevated causeway tests at Coronado, California. The data from these tests have been grouped according to the type of craft used to impact the fender. The LCU data (see Table 1-1) were obtained when the lighter came alongside the pierhead to discharge or receive empty and loaded containers. For some of his approaches, the pilot was asked to deliberately hit the fender with more force than was necessary to make a normal berthing under

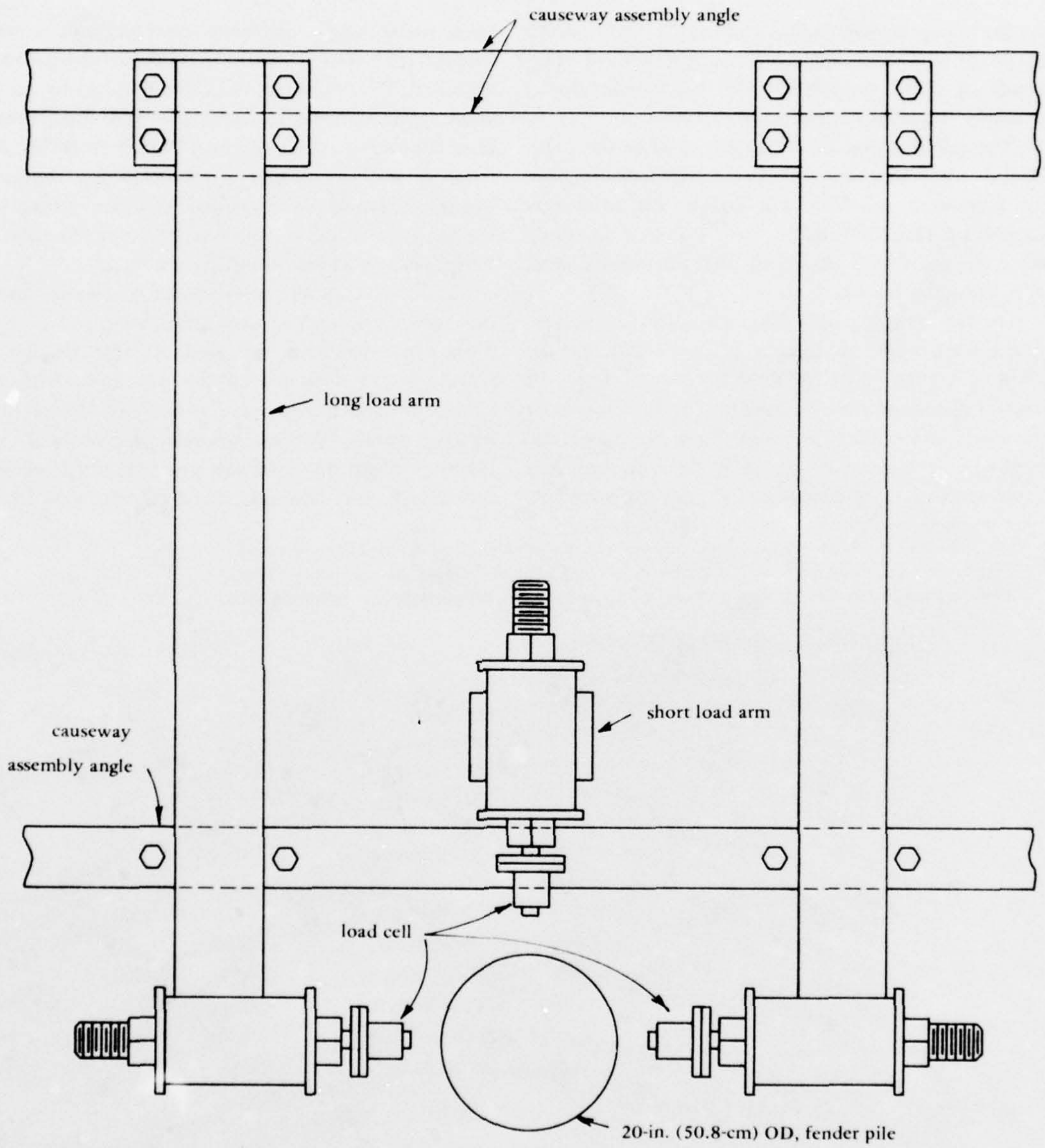


Figure 1-17. Load arm arrangement of each instrumented pile. Load cells are positioned to bear directly on pile prior to impact tests.

the prevailing environmental conditions. None of the recorded pile reactions, however, exceeded a magnitude of 6,900 pounds (30,700 N), which reflects primarily the caution of the LCU pilot.

The pile reaction forces measured while the LCU, LCM-8, and causeway ferry were berthed alongside the pier were nil. This was due to the calm seas [waves 1.5 feet (0.46 m) high or less] and an alongshore current which tended to hold the moored craft away from the fender.

On the morning of 4 December 1975, arrangements were made to have a 112-ton (101,600-kg) warping tug from PHIBCB-ONE make a series of bow-on approaches to the fender. The first approach was made at 5 knots (2.6 m/sec),* and the tug hit the seaward-most foam cushion on fender unit one. The result was a jarring impact which was estimated to have momentarily displaced the pierhead 4 to 6 inches (10.2 to 15.2 cm). The kinetic energy to be absorbed,** 248,000 lb-ft (336,000 N·m) by far exceeded the maximum rated capacity of the Seaward International foam cushion [39,000 lb-ft (52,800 N·m) at 50% compression]. Much of the energy at impact, however, was absorbed by other elements of the fender system e.g., the floating 1x15 NL pontoon string, the fender piling, and the pierhead.

Some damage was sustained by the fender due to the first impact. The seaward-most pile was bent inward at the point of contact with the fender (Figure 1-21). This forced the pile away from the load cells atop the pierhead so that no further force readings on Pile A were possible. The outboard top assembly angle on the 1x15 string was bent as were several of the framing members in the fender

*Verified by the hand-held "speed gun." However, some error in this figure is to be expected.

**No allowance was made for added-mass effects in computing the impact kinetic energy. The added-mass for the shallow-draft tug impacting against the pile-supported pier would be small.

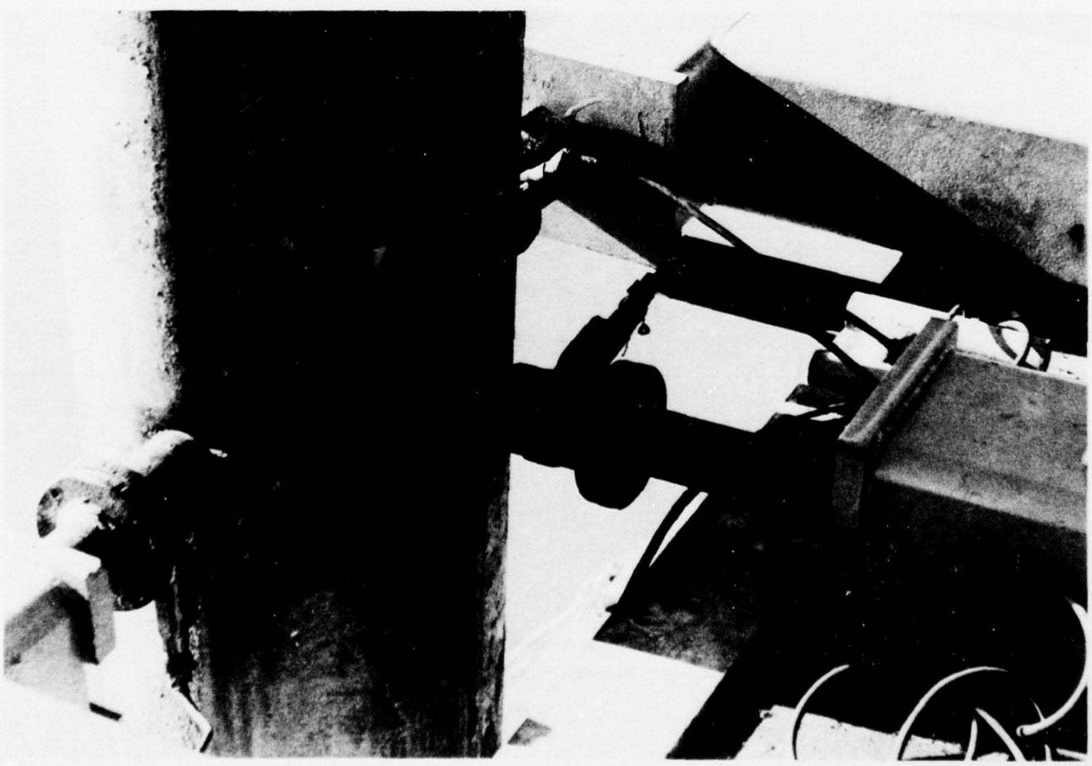
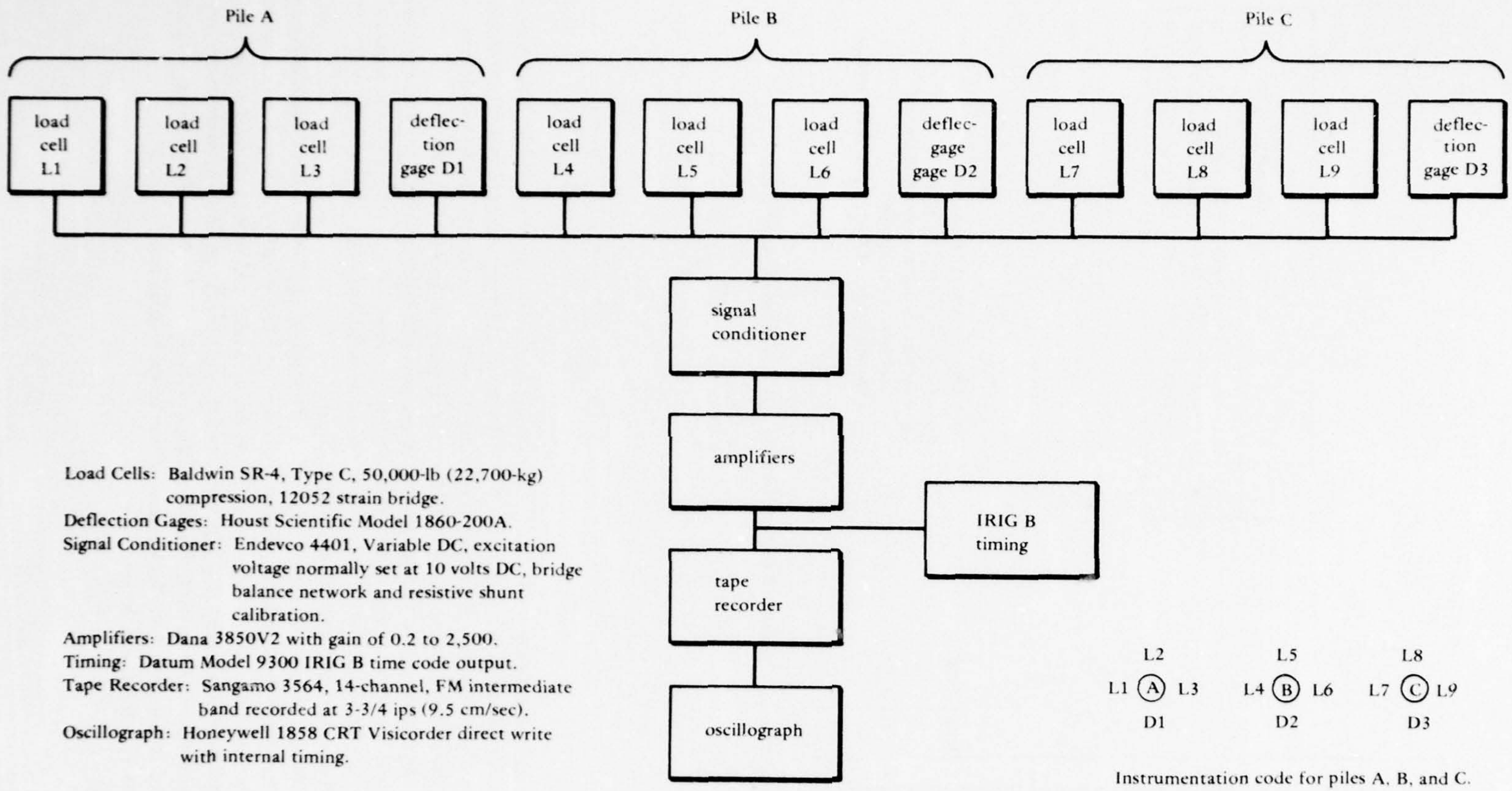
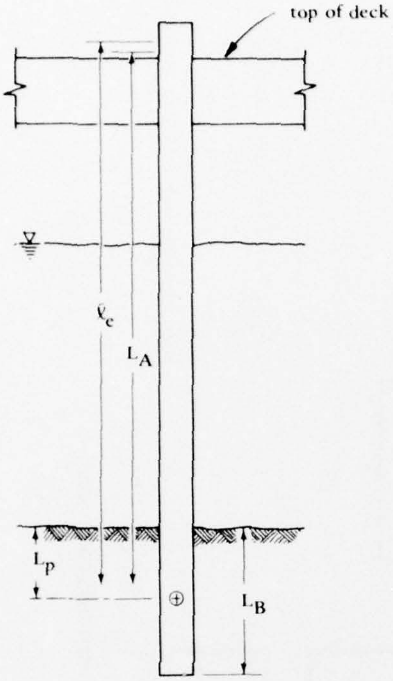


Figure 1-18. Pile instrumentation setup.



Load Cells: Baldwin SR-4, Type C, 50,000-lb (22,700-kg) compression, 12052 strain bridge.
Deflection Gages: Houst Scientific Model 1860-200A.
Signal Conditioner: Endevco 4401, Variable DC, excitation voltage normally set at 10 volts DC, bridge balance network and resistive shunt calibration.
Amplifiers: Dana 3850V2 with gain of 0.2 to 2,500.
Timing: Datum Model 9300 IRIG B time code output.
Tape Recorder: Sangamo 3564, 14-channel, FM intermediate band recorded at 3-3/4 ips (9.5 cm/sec).
Oscillograph: Honeywell 1858 CRT Visicorder direct write with internal timing.

Figure 1-19. Schematic drawing of pile instrumentation setup.



Pile	L_B (in., cm)	ℓ_e (in., cm)	L_A (in., cm)	L_p (in., cm)
A	154 (391)	567 (1,440)	558 (1,417)	92 (234)
B	151 (384)	547 (1,389)	538 (1,367)	114 (290)
C	140 (356)	539 (1,369)	530 (1,346)	148 (376)

ℓ_e – Effective length of pile
L_B – Depth of pile embedment
L_A – Distance between point of fixity and load cell reaction point.
L_p – Distance point of fixity lies beneath seafloor

Figure 1-20. Results of pile calibration test – Coronado, California.

spudwell surrounding the failed piling.

The tug pilot was then instructed to hit the instrumented fender at approximately the center pile position. He was also cautioned to reduce his speed of approach. Again, the tug compressed a single cushion, the fourth cushion from the seaward end. The speed at impact was about 2.5 knots (1.3 m/sec), and the effects atop the pierhead were far less intense than those noted during the initial test impact. A visual check after the tug had backed-off did not disclose any further damage to the fender.

On the third and final approach, the tug was clocked at a speed of 5 knots (2.6 m/sec), the same impact speed observed in the first test. This impact resulted in damage to Pile B. It was decided to terminate further testing of the fender, since several load cells were no longer making contact with the failed A and B piles. A summary of the warping tug impact data appears in Table 1-2. Note that in each of the three tests the estimated maximum bending moment in one or more of the fender piles exceeds the calculated yield moment of 333,900 lb-ft (452,400 N·m).

Damage to the fender system was confined to pile failure, a bent 6-inch (15.2-cm) NL pontoon top assembly angle, and several buckled flanges on structural members in the seaward-most spudwell. However, the fender was still functional after completion of the impact tests.

Figure 1-21. Failed fender pile.

Table 1-1. Summary of Fender Pile Impact Loads and Moments – LCU Tests

Test No.	Maximum Measured Pile Reaction Force Normal to Pier (lb, N)			Estimated Maximum Force in Piling at Fender Level (lb, N)			Estimated Maximum Moment in Piling (lb-ft, N·m)		
	Pile A[c]	Pile B[d]	Pile C[e]	Pile A	Pile B	Pile C	Pile A	Pile B	Pile C
1[a]	5,800 (25,800)	0	6,400 (28,500)	11,000 (48,900)	0	13,700 (60,900)	95,000 (128,800)	0	106,000 (143,700)
2[b]	6,900 (30,700)	2,400 (10,700)	4,300 (19,100)	14,100 (62,700)	4,800 (21,400)	9,500 (42,300)	114,000 (154,600)	38,000 (51,500)	73,000 (99,000)
3[b]	4,200 (18,700)	700 (3,100)	1,600 (7,100)	13,100 (58,300)	2,300 (10,200)	6,100 (27,100)	96,000 (130,200)	16,000 (21,700)	39,000 (52,900)

[a] LCU unloaded.

[b] LCU with two empty and two loaded containers aboard.

[c] Pile A: Seaward-most pile.

[d] Pile B: Middle pile.

[e] Pile C: Shoreward-most pile.

Table 1-2. Summary of Fender Pile Impact Loads and Moments — Warping Tug Tests

Test No.	Maximum Measured Pile Reaction Force Normal to Pier (lb, N)			Estimated Maximum Force in Piling at Fender Level (lb, N)			Estimated Maximum Moment in Piling (lb-ft, N-m)		
	Pile A[a]	Pile B[b]	Pile C[c]	Pile A	Pile B	Pile C	Pile A	Pile B	Pile C
1	31,000 (137,900)	29,300 (130,300)	700 (3,100)	52,700 (234,400)	50,700 (225,500)	1,400 (6,200)	406,000 (550,100)	381,000 (516,300)	10,000 (13,500)
2	d	25,800 (114,800)	4,100 (18,200)	d	45,500 (202,400)	7,600 (33,800)	d	344,000 (466,100)	58,000 (78,600)
3	d	38,900 (173,000)	33,400 (148,600)	d	71,800 (319,400)	61,700 (274,400)	d	551,000 (746,600)	467,000 (632,800)

[a]Pile A: Seaward-most pile.
[b]Pile B: Middle pile.
[c]Pile C: Shoreward-most pile.
[d]Pile A damaged in Test No. 1.

Note: Calculated yield moment in piling: 20-in. (50.8-cm) OD, 3/8-in. (0.95-cm) wall thickness = 333,900 lb-ft (452,400 N-m)
20-in. (50.8-cm) OD, 1/2-in. (1.27-cm) wall thickness = 437,100 lb-ft (592,300 N-m)

SECTION 4

EVALUATION OF TEST RESULTS

1.4.1 ENERGY ABSORPTION

A standard measure of fender system effectiveness is the capability to absorb the kinetic energy of berthing vessels:

$$KE = \frac{1}{2} mV^2$$

where m is the mass of the vessel, and V is the normal velocity at initial contact with the fender. The added-mass of the accelerated water will be ignored for the shallow-draft COTS lighterage berthing against the open, pile-supported pier. Therefore, the kinetic energy of the PHIBCB-ONE warping tug is estimated to have been 62,000 lb-ft (84,000 N·m) for the 2.5-knot (1.3-m/sec) impact and 248,000 lb-ft (336,000 N·m) for the two impacts at 5.0 knots (2.6 m/sec). Since the tug approached bow-on to the fender and its forward motion was fully arrested, all of this kinetic energy must have been absorbed by the fender and pierhead. Although the warping tug was observed to contact a single 7.4-foot (2.3-m) foam cushion on each of the trial impacts, in a normal berthing situation, with the craft approximately abreast of the fender at berthing, the COTS lighters can be expected to contact at least two cushions.

The rated energy absorption of a single Seaward International 4.0-foot (1.2-m) by 7.4-foot (2.3-m) cushion is 39,000 lb-ft (52,800 N·m) at 50% compression. These cushions can sustain occasional impacts to 70% compression with a resulting energy absorption capacity of approximately 2.9 times that at 50% compression, i.e., about 114,000 lb-ft (154,000 N·m). Thus, for two cushions, the energy absorption capacity is 78,000 lb-ft (10,600 N·m) and 228,000 lb-ft (309,000 N·m), respectively at 50% and 70% compression.

The estimated warping tug impact energies encountered during the Coronado tests, the rated energy absorption of the foam cushions, and the computed impact energies for two classes of COTS lighterage are summarized in Figures 1-22 and 1-23. The displacements for the two COTS lighters, an LCM-8 and a 1610 Class LCU, are presented in Table 1-3.

Table 1-3. Displacements for Lighters Used in Berthing Energy Absorption Summary

Condition	Displacement (long tons, kg) for –	
	LCM-8	LCU
Light ship	51.3 (52,100)	185 (188,000)
Four MILVANs aboard	–	265 (269,200)
Full load	103 (104,600)	342 (347,500)

In Figure 1-22, kinetic energy at impact as a function of speed normal to the fender is plotted. Horizontal broken lines that represent the design energy absorption of the foam cushions and the measured berthing impact energies at Coronado also appear on the graph.* Each of the five lighterage cases is represented by a curve which is a plot of the berthing impact energy, (1/2) mV^2.

In Figure 1-23, the abscissa has been changed from impact speed in knots (m/sec) to lighterage displacement in long tons (kg). This plot can be used to estimate the impact energy for any class of lighterage provided the displacement and speed normal to the fender are known.

It is evident from Figure 1-22 that the kinetic energy to be absorbed when the heaviest lighter (LCU with full load) impacts the fender can be easily accommodated for speeds of up to 2 fps (0.61 m/sec). This kinetic energy level [47,600 lb-ft (64,500 N·m)] is within the design specifications of the fender cushions and is less than the input energy observed during the second of the warping tug impacts at Coronado in which no damage was observed to occur.

*The foam cushions, of course, absorb only a portion of the total berthing energy.

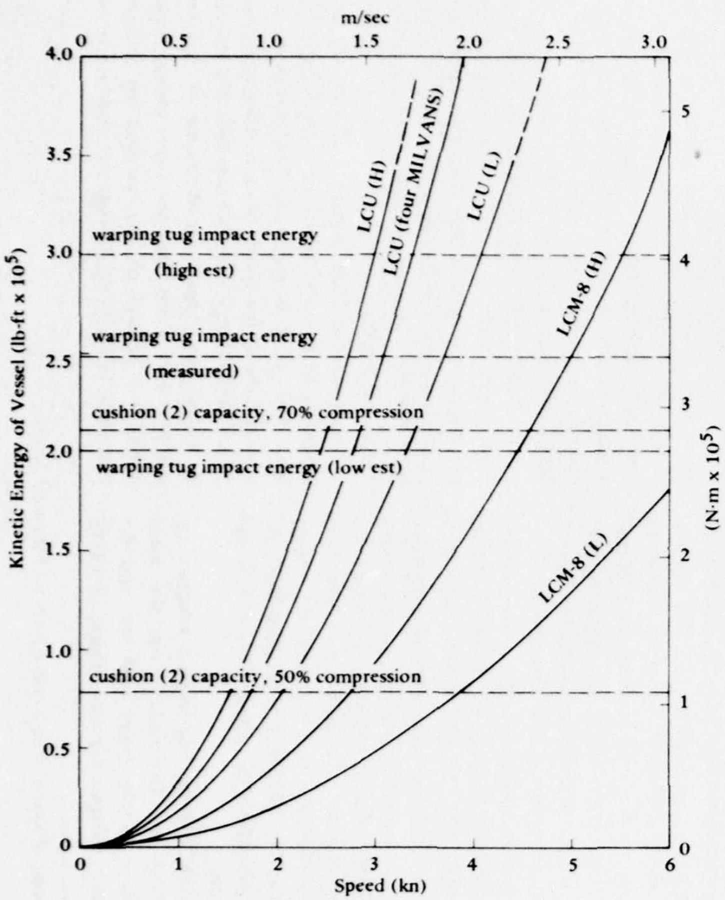


Figure 1-22. Kinetic energy of vessel as a function of berthing speed.

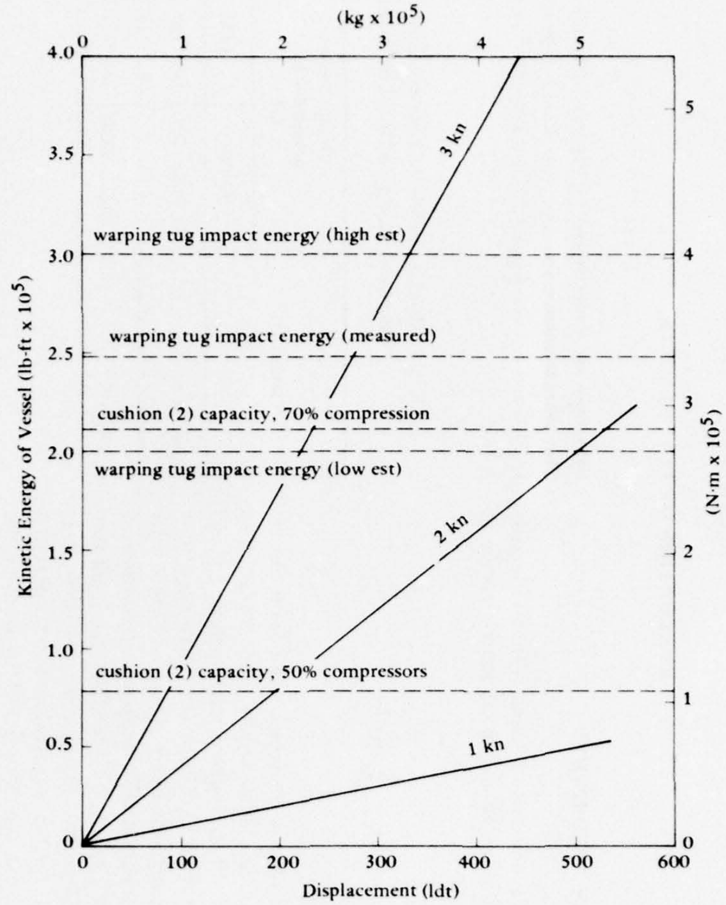


Figure 1-23. Kinetic energy of vessel as a function of displacement.

It would take a normal impact velocity of 2.75 knots (1.42 m/sec) for the fully loaded LCU to produce an impact comparable to that produced by the warping tug at 5 knots (2.6 m/sec).

In summary, the fender system employed at Coronado can easily absorb the berthing energy induced by the heaviest class of lighterage at normal velocities of up to 2 fps (0.61 m/sec) and even greater speeds for craft with lighter displacement. Although fender damage can be expected at higher berthing speeds, the fender can tolerate considerably heavier impact and still function. The damage threshold has not been precisely determined, but based upon the measured pile reaction loads at Coronado, the critical impact energy is probably not much less than the 248,000 lb-ft (336,000 N·m) observed for the first and third warping tug tests.

As is true of any fender system, damage or even complete destruction is possible if the berthing impact energy is great enough. The elevated causeway fender, especially with the design improvements to be discussed later, is considered adequate to handle normal berthing loads of COTS lighterage.

1.4.2 DESIGN IMPROVEMENTS

In general, the fender configured for the Phase I and Phase II tests performed well. The tests did indicate that the performance of the system could be improved if mooring bitts or chain plates were included to aid line handlers during installation and removal of the fender.

Since the outboard 6-inch (15.2-cm) top assembly angle was damaged during the impact tests at Coronado, it is recommended that future elevated causeway fender units be assembled with the 8-inch (20.3-cm) assembly angles. This will result in a substantial increase in moment resistance.

In all future fender installations, piles having a minimum wall thickness of 1/2 inch (1.27 cm) should be used.

Figures 1-24 and 1-25 are assembly drawings that include the aforementioned improvements as well as additional minor changes, such as stronger vertical strap padeyes for rigging the foam cushions. Two rigging configurations are depicted: one with six 4 x 7.4-foot (1.2 x 2.3-m) Seaward International foam cushions, and the other having three 4 x 10-foot (1.2 x 3-m) and two 4 x 8-foot (1.2 x 2.4-m) Ocean Systems cushions. Figure 1-26 details the internal spudwells, three of which are needed for each 1x15 fender string.

1.4.3 COSTS

The cost of a single 1x15 fender string is summarized in Table 1-4. The estimate includes the labor cost to assemble the 1x15 NL pontoon string and to rig the foam cushions, but it does not include the cost of post-assembly handling and installation.

Table 1-4. Cost Estimate for a 1x15 Fender String

Component	Cost ($)[a]
Material	
NL Pontoon equipment, e.g., pontoons, assembly angles, etc.	20,000
Foam cushions (6)	25,200
Internal spudwells with chafing ring (3)	15,900
Rigging hardware	1,500
Miscellaneous hardware, e.g., padeyes, mooring bitts, etc	2,500
External spudwells, bolted to pierhead (3)	8,400
Piles, 60 ft long, 1/2 in. wall thickness (3)	7,200
Subtotal	80,700
Labor	
Pontoon assembly	1,000
Cushion rigging	1,000
Miscellaneous welding	500
Subtotal	2,500
Total	83,200

[a]Costs based on 1976 figures.

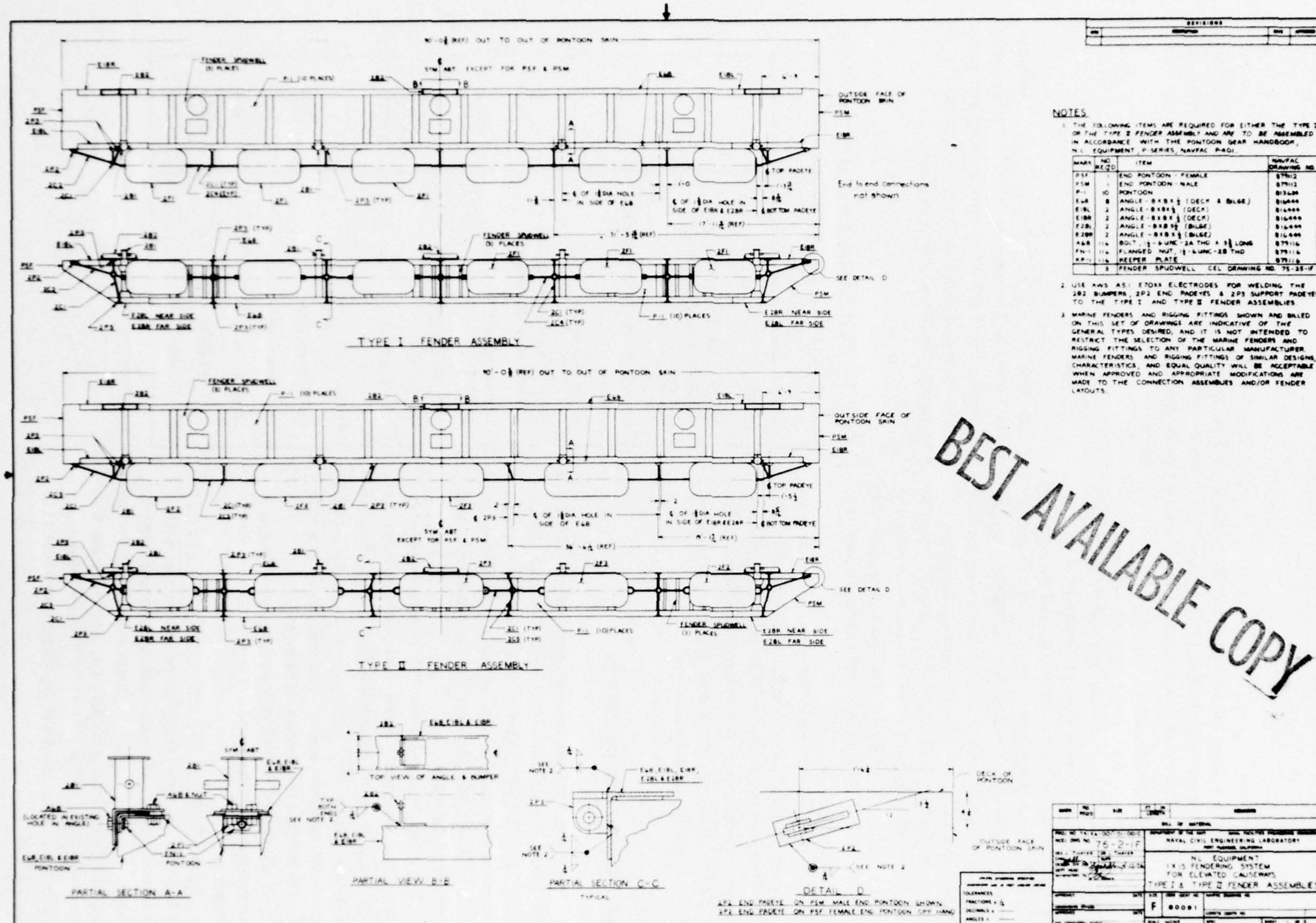


Figure 1-24. Assembly drawing for 1x15 fender system.

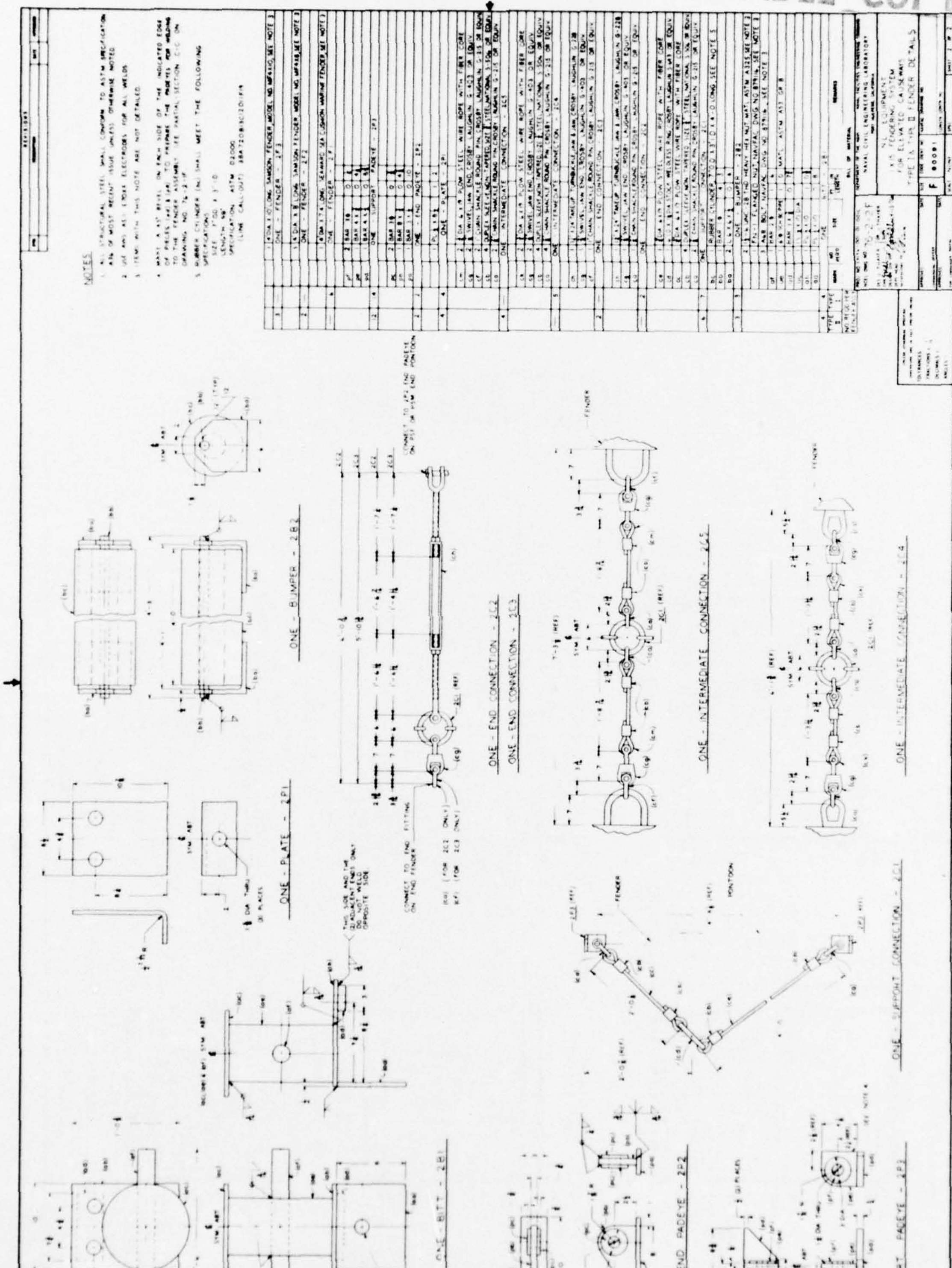


Figure 1-25. 1x15 fender system — rigging detail.

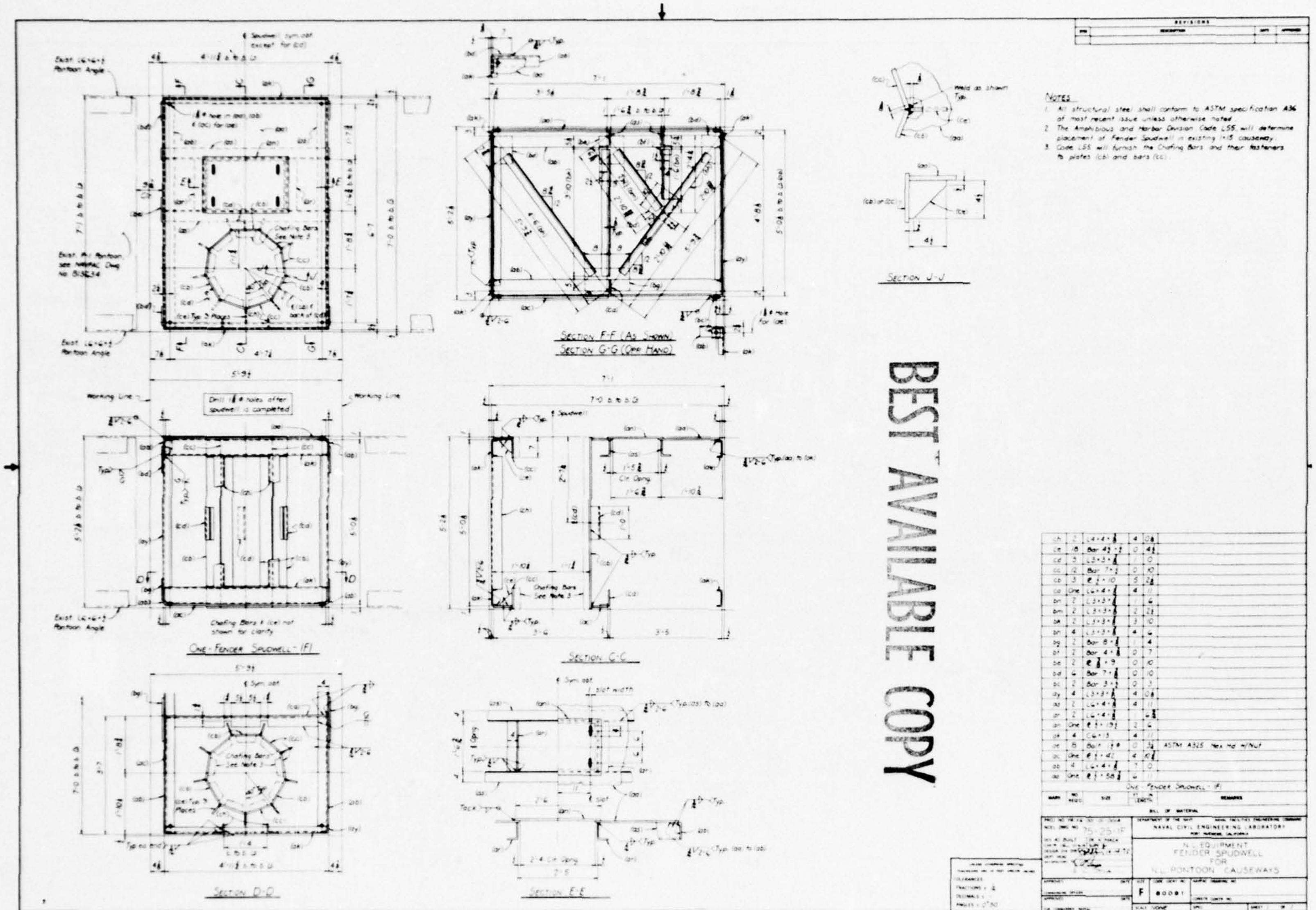


Figure 1-26. Assembly drawing for fender spudwell.

1.4.4 WAVE-INDUCED MOTION

The calm sea conditions existing at the time of the fender installation at Coronado did not induce significant motion to either the fender or its warping tug tender.* What would happen if the sea conditions were more severe? In an effort to answer this question, the CEL-developed ship motion computer program** was used to predict the motion of a single 1x15 fender string. This analytical model is based on strip theory and uses deep water added-mass and damping terms in the equation of motion. The following assumptions were made in the analysis:

- The 1x15 is floating free and is unrestrained by either the warping tug or piling.
- The mean water depth is 20 feet (6.1 m) (approximate average depth at the pierhead).
- Two wave headings are considered: stern-on to the fender and 15 degrees off the port stern (the stern is assumed to be the seaward end of the fender).

The results of the motion analysis are presented in Figures 1-27 and 1-28. The point of interest (the point at which the motion is computed) is on the top of the 1x15 string at the forward port corner, a likely location for securing a spring line during fender mooring. The results appear as period-dependent longitudinal, transverse, and vertical displacement response amplitude operators (RAOs), i.e., displacement per foot (or meter) of incident wave amplitude. The theory is linear so that estimates of fender motion for waves of any given amplitude can be found by taking the product of the wave amplitude and the RAO. Thus, in Figure 1-27, for a 6-foot (1.8-m) high, 16-second wave, the longitudinal motion at the point of interest is:

$$\text{Displacement} = \text{RAO} \times \text{wave amplitude}$$

$$= 3.0 \times 3.0 = 9.0 \text{ feet } (2.7 \text{ m})$$

The total excursion fore and aft is twice this value, or 18.0 feet (5.5 m).

In practice the fender would be restrained somewhat by the warping tug during mooring and retrieval, but nevertheless it can be seen that considerable fender motion, especially in surge, is possible during installation when a long-period swell is present.

*See Volume I for environmental observations

**See CEL Technical Note N-1371: The motion of floating advanced base components in shoal water – A comparison between theory and field test data, by D. A. Davis and H. S. Zwibel, Port Hueneme, California, Jan 1975.

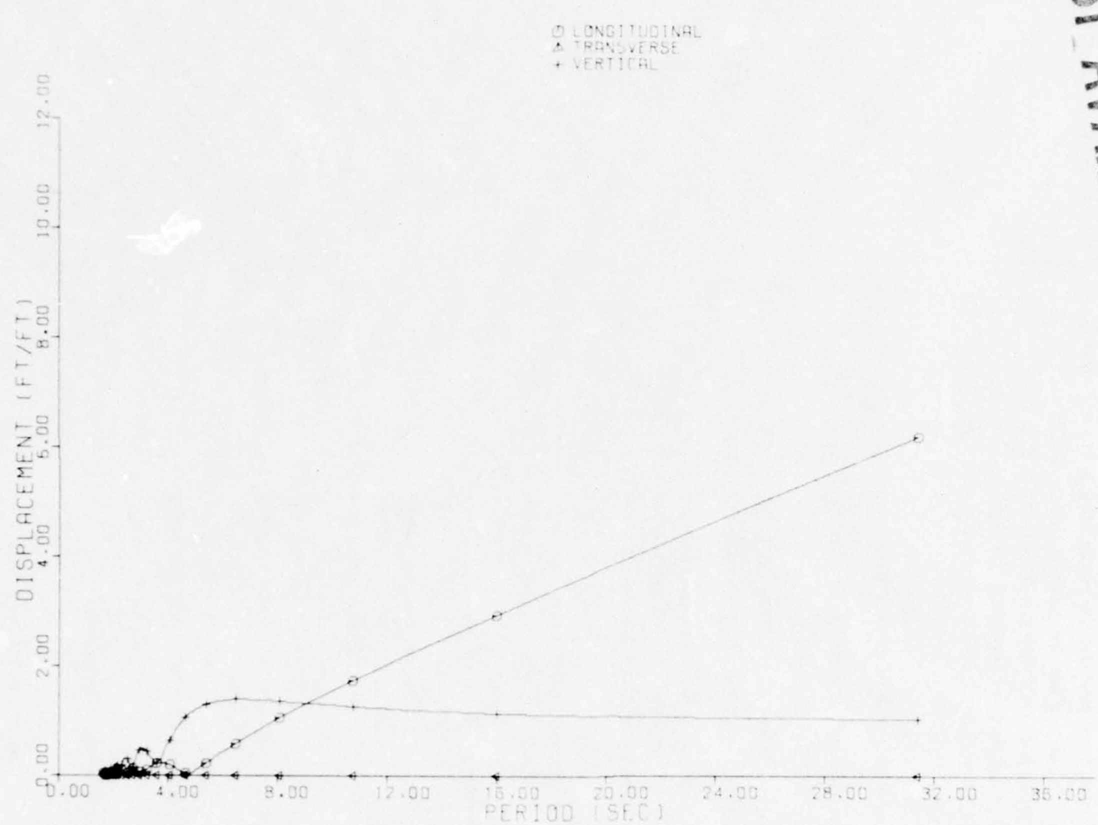


Figure 1-27. Wave-induced motion of a 1x15 NL fender – waves stern-on.

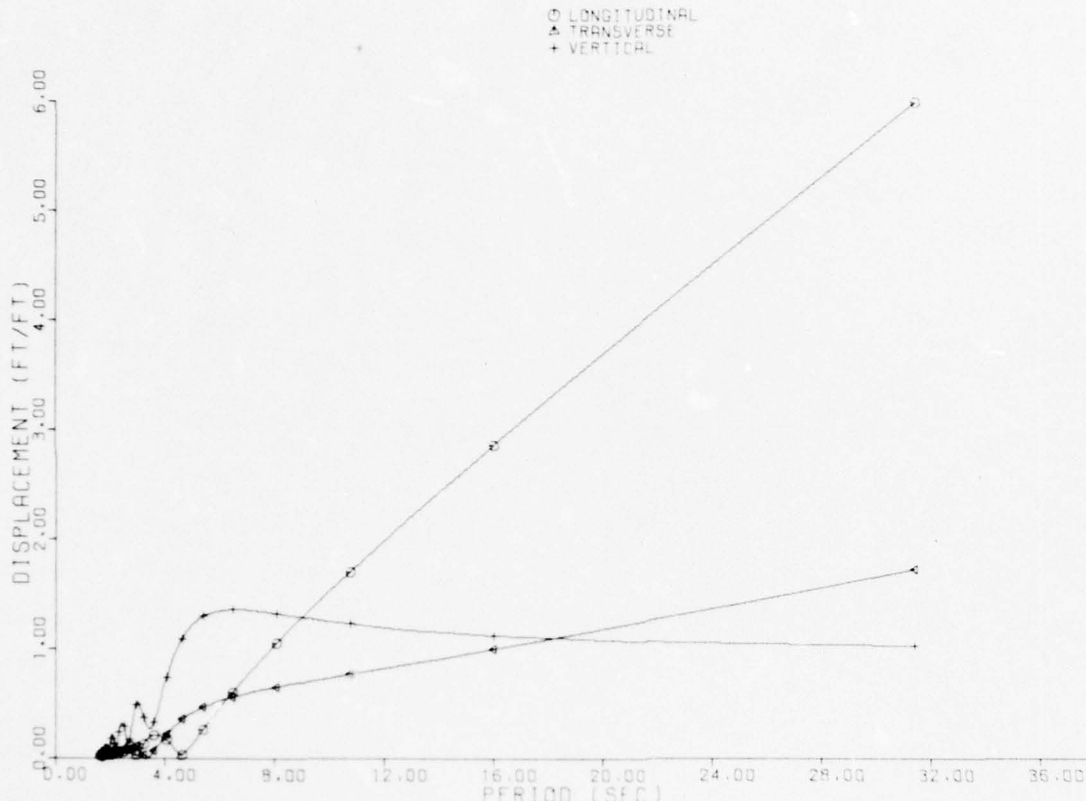


Figure 1-28. Wave-induced motion of a 1x15 NL fender – waves 15 degrees off port stern.

SECTION 5

FINDINGS AND CONCLUSIONS

1. During Phase II of the elevated causeway tests, the fender system withstood, without damage, a 2.5-knot (1.3-m/sec) bow-on impact by PHIBCB-ONE's 112-ton (101,600-kg) warping tug. The fender survived, with some damage to the restraint piles and one top assembly angle, a 5-knot (2.6-m/sec) impact by the same craft.

2. Based upon the impact test results and performance during the container unloading phase of the elevated causeway tests, it is conservatively estimated that the elevated causeway fender can absorb the berthing impact from a fully loaded 1610 Class LCU having a normal impact velocity of 2 knots (1.0 m/sec).

3. On several occasions the fender system survived 8-foot (2.4-m) seas without damage. The fender system for the elevated pier has been designed to survive waves up to 10 feet (3.0 m) in height. Careful inspection of the fender system after 45 days of service at Coronado suggests that the fender would remain operational for the 6-to-12-month period projected as the operational lifetime for the COTS elevated pier system.

4. The commercial foam-filled cushions effectively cushion berthing impact. After 45 days in place at Coronado, the cushions exhibited no evidence of substantial wear or degradation of performance. One cushion sustained a 9-inch (22.9-cm) tear in the outer covering which, however, was judged easy to repair.

5. Commercial foam-filled cushions having a solid steel core are adequate for the elevated causeway fender application. An experimental cushion that was tested at Coronado and is designed to compress longitudinally offers no special advantages over conventionally constructed cushions.

6. On the basis of wearing properties and resistance to exposure to the saltwater environment, the rubber chafing plates used on the seaward-most fender are a far better choice than the oak planks used on the shoreward-most fender.

7. Mooring bitts or chain plates on the fender are required to aid line handlers during installation and removal.

8. Pile guides, which are installed in the external spudwells on the pierhead prior to insertion of the restraint piles, are effective devices for vertically aligning the piles.

9. A long-period swell could induce excessive surge motion of the fender system which would add greatly to the difficulty encountered during installation and removal.

CHAPTER 2

ABSOLUTE LIGHTERAGE MOTIONS*

2.1 INTRODUCTION

Seakeeping tests were conducted on various lighters participating in the elevated causeway tests at Coronado. The purpose of the seakeeping tests was to obtain data that could be used to evaluate the effects of wave-induced motions on the off-loading and loading procedures.

The objectives of the David Taylor Naval Ship Research and Development Center (DTNSRDC) Ship Performance Department during the trials were to:

- Measure and analyze wave height data obtained from a Waverider buoy system and from a fixed ultrasonic probe attached to an outboard elevated causeway section.
- Measure and analyze lighter absolute motion data taken when the vessels are alongside the elevated causeway.

The results of the measurements are presented in tabular and graphical form in order to aid in the evaluation of the various lighters. This evaluation, however, is limited by the magnitude of the swell wave heights encountered during the operations.

2.2 LIGHTER CHARACTERISTICS

The lighters involved in the operations included: (1) a three-section causeway ferry tied to a warping tug; (2) a LCM-8, and (3) a 1626 Class LCU.

2.2.1 Floating Causeway Sections and Warping Tug

The causeway ferry and warping tug system were tied alongside the fender systems as seen in Figure 2-1. Each causeway section is 21 feet (6.4 m) wide by 90 feet (27.4 m) long with a draft of 1.33 feet (0.41 m). The displacement of each causeway section is 137,000 pounds (62,000 kg) while the warping tug displacement is 224,000 pounds (102,000 kg).

2.2.2 Navy LCM-8 and LCU

The LCM-8 and the 1652 LCU were also tied alongside the fender system for off-loading and loading of containers as seen in Figures 2-2 and 2-3, respectively. The LCM-8 has a light displacement and length of 115,000 pounds (52,000 kg) and 74 feet (22.6 m), while the light displacement and length of the 1652 LCU are 455,000 pounds (206,000 kg) and 135 feet (41.4 m) respectively.

2.3 TEST CONFIGURATIONS AND INSTRUMENTATION

Table 2-3 lists the date, run number, and vehicles involved in a particular off-loading or loading exercise at the Coronado test site. The table also indicates which particular seakeeping measurement was made during the exercises.

Motions were measured on the various lighters using either the DTNSRDC motion measuring package or the Humphrey stable platform package. The DTNSRDC motion package consisted of a gyroscope to measure pitch and roll and three hard-mounted Donner accelerometers to measure surge, heave, and sway accelerations. The Humphrey motion package consisted of a Honeywell gyroscope to measure pitch and roll and three gyro-stabilized accelerometers to measure surge, heave, and sway accelerations. Figures 2-4 through 2-8 indicate the placement of either the DTNSRDC package or the Humphrey platform on the various vehicles for each trial run. Figure 2-9 shows the Humphrey platform mounted on the LCM-8.

Wave height was measured with the CEL Datawell Waverider buoy. The wave height data were telemetered from the buoy to the instrumentation van located on the outboard end of the elevated causeway. This buoy was moored about 250 yards (229 m) from the elevated causeway in 25 feet (7.6 m) of water. Wave height was also measured using a Wesmar ultrasonic transducer fixed to the outermost edge of the elevated causeway (Figure 2-10).

*As reported by Lawrence C. Ruth, of DTNSRDC. For additional details of the motion measurements, see DTNSRDC Report SPD-515-02: On investigation of the absolute vehicle motions involved in the container off-loading and transfer system (COTS) trials, by Lawrence C. Ruth, Mar 1976.

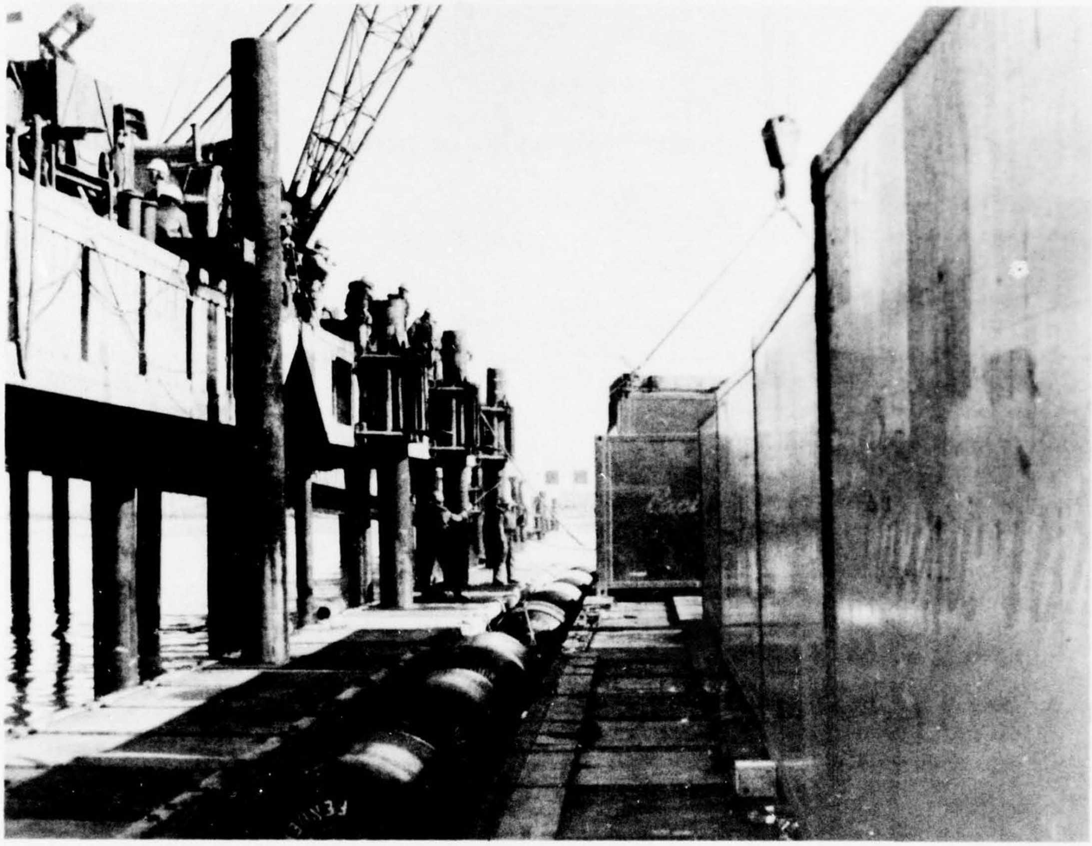


Figure 2-1. Off-loading containers from floating causeway sections alongside elevated causeway.

All data were recorded on analog tape and strip charts.

2.4 TEST RESULTS

Table 2-2 presents the significant ship motions and wave height for each run made during the elevated causeway tests. The significant values for all channels are obtained from the response spectra, where the significant value is defined as the average of the one-third highest peak-to-peak excursions for a particular channel during a test run. For the majority of the test runs, all lighters remained fully loaded so that a steady-state displacement could be obtained. Data were recorded for a sufficient period of time to obtain a good statistical sample of information.

Figures 2-11 and 2-12 compare wave height spectra obtained from the buoy and the ultrasonic probe for several test runs. All spectra are point spectra.

2.5 DISCUSSION

Due to the very moderate weather that prevailed during the tests, all runs were made in very low seas. The wave height spectra in Figures 2-10 and 2-11 indicate that most of the energy in the seaway was from a predominant swell component with a period

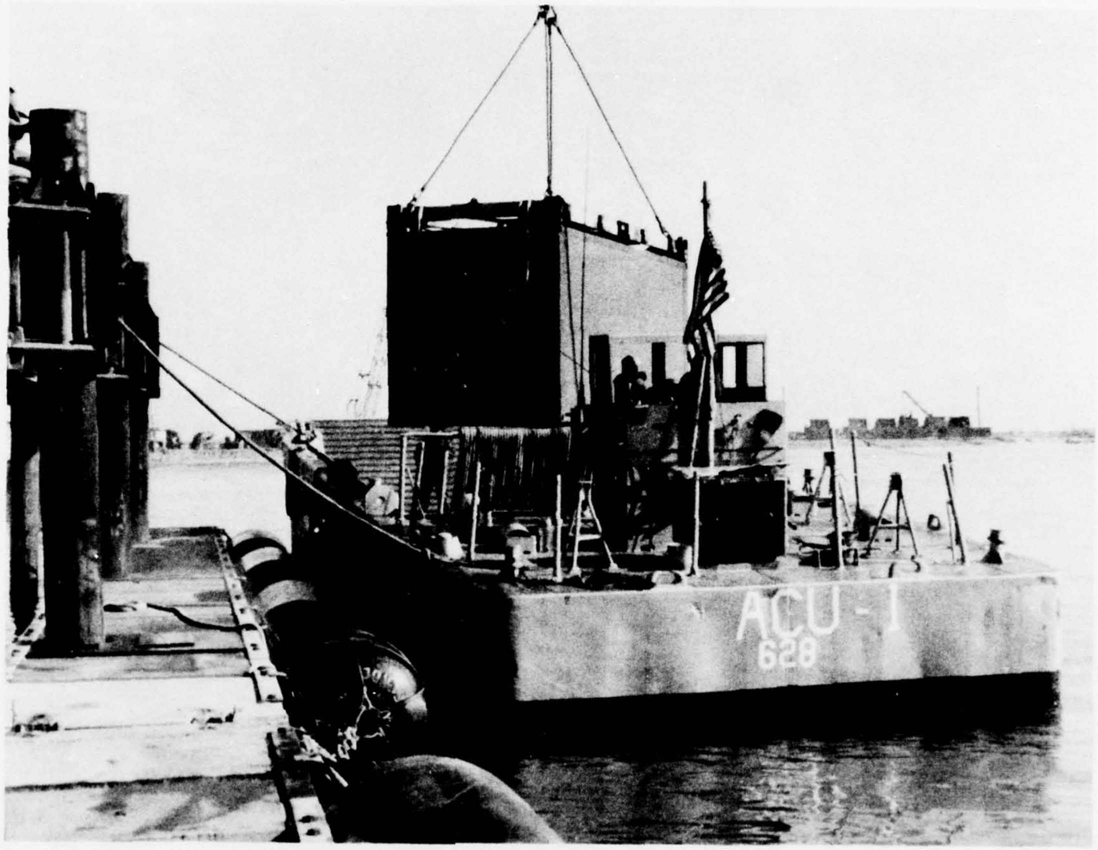


Figure 2-2. Off-loading containers from LCM-8 alongside elevated causeway.

of approximately 14 seconds. There was very little energy in the higher frequency components of the seaway. In fact, the maximum significant wave height recorded during the 4 days of container unloading tests was 1.85 feet (0.56 m). Very good agreement was obtained between the buoy and ultrasonic probe wave height spectra. For the most part the ultrasonic significant wave height was slightly less than that obtained by the buoy as can be seen in Table 2-2.

As a result of the low seaway, very small motion levels were obtained on the lighters used during the operations. Table 2-2 indicates that the maximum significant pitch of 2.38 degrees occurred on the LCM-8. Also extremely small translational accelerations were obtained on all lighters during the tests. Thus, the heave, surge, and sway translations during the tests were all seen to be almost negligible. The most noticeable motion on all the lighters was pitch, and these magnitudes are presented in Table 2-2.

A better evaluation of the effect of waves and motions on the transfer system could have been made if the seaway had been of a larger magnitude.

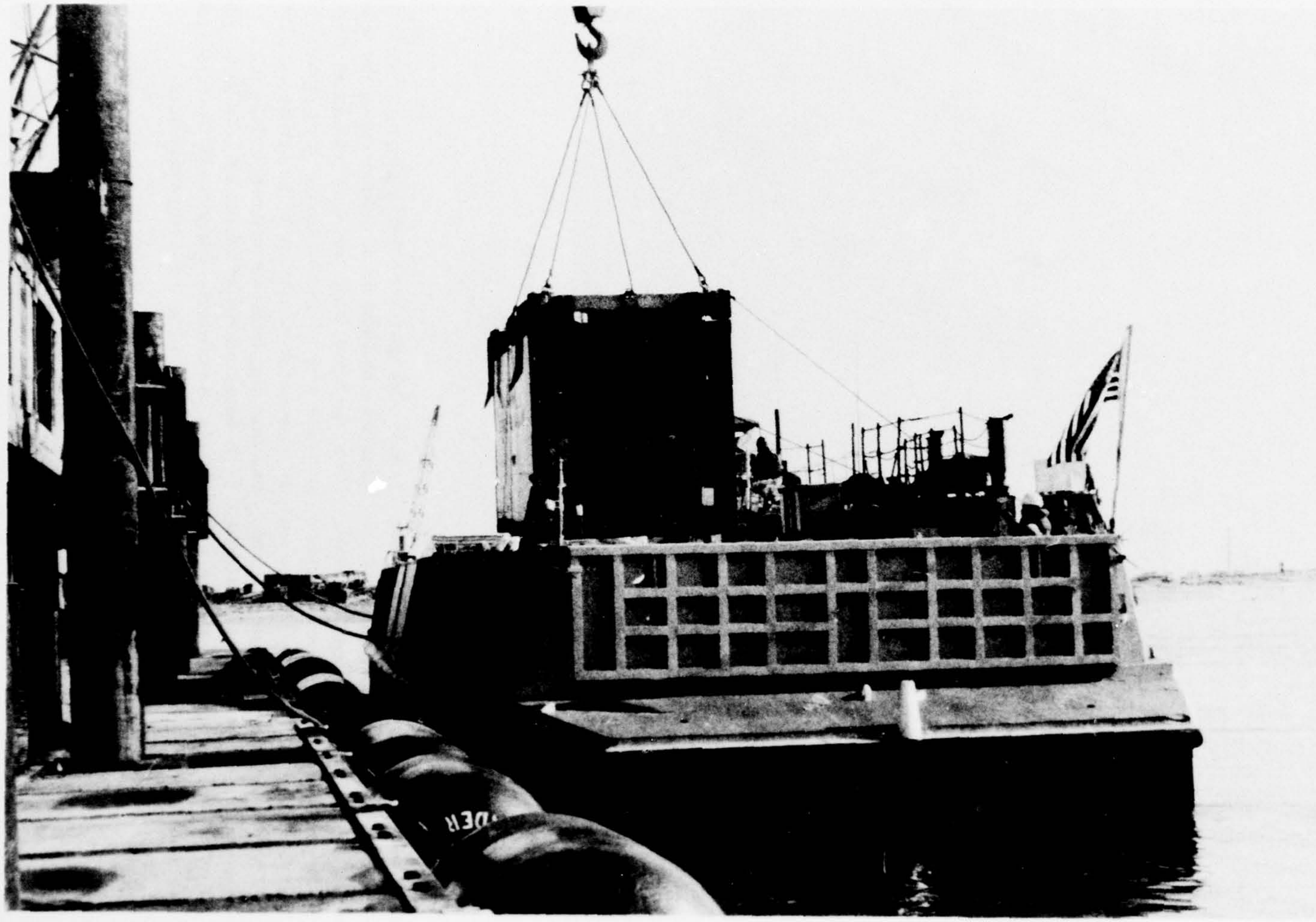


Figure 2-3. Off-loading containers from Class 1652 LCU alongside elevated causeway.

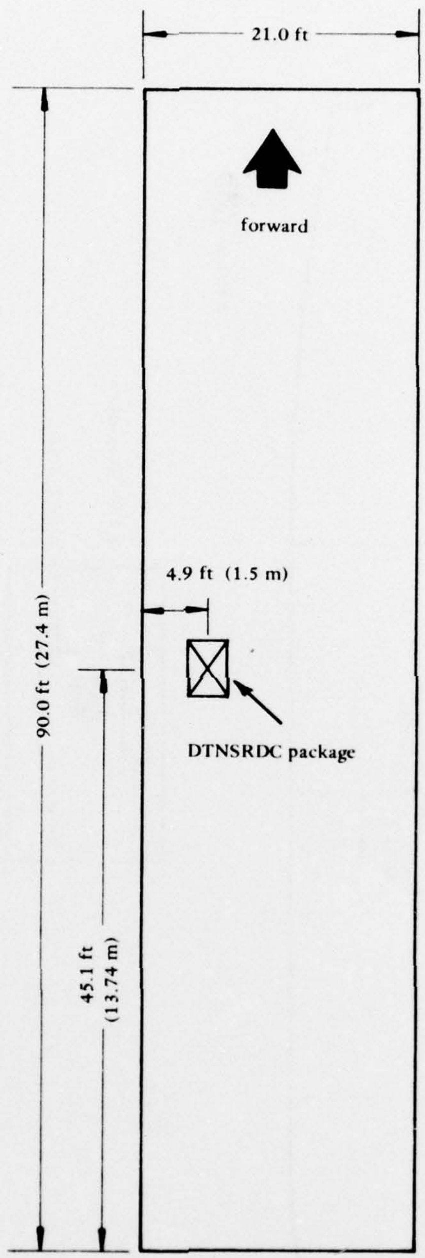


Figure 2-4. DTNSRDC motion package on aft causeway section for runs 1, 4, 5, and 6.

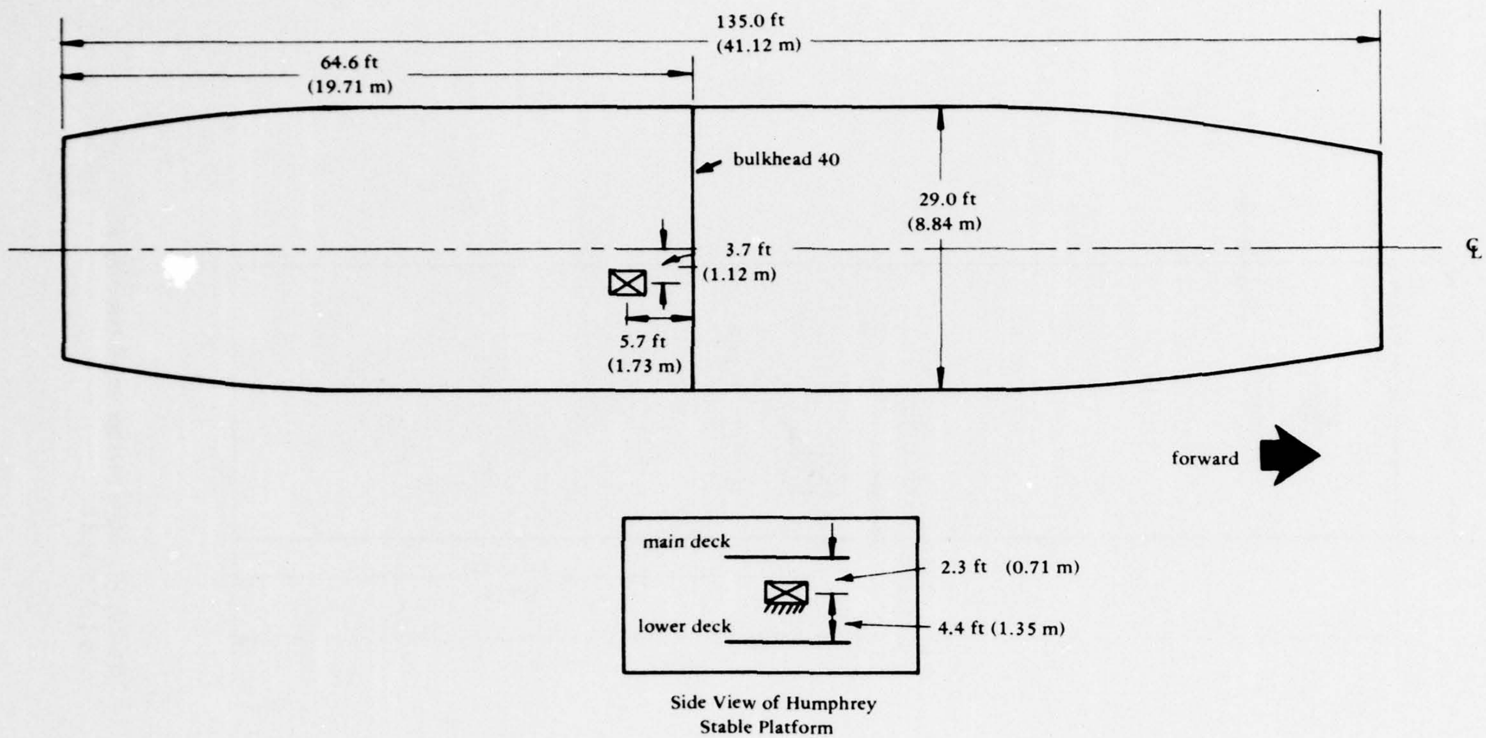


Figure 2-5. Humphrey stable platform location on 1652 LCU for runs 8, 9, and 13.

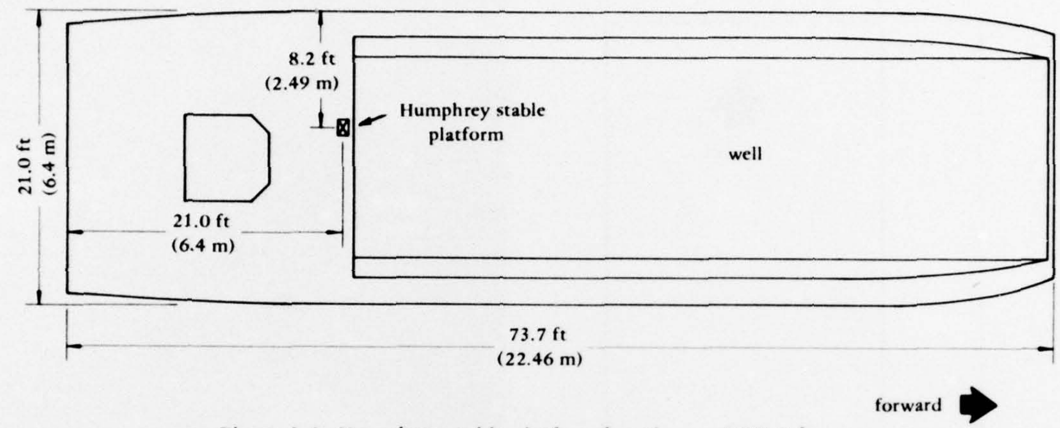


Figure 2-6. Humphrey stable platform location on LCM-8 for runs 11 and 14.

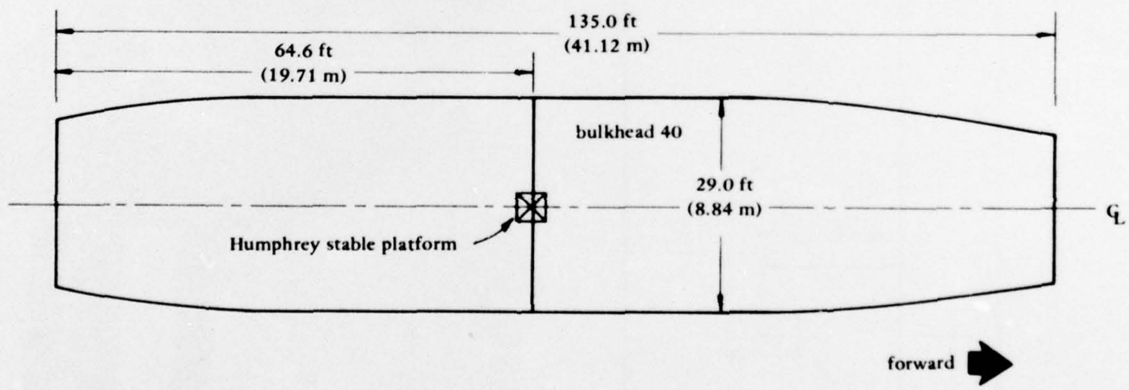


Figure 2-7. Humphrey stable platform location on 1652 LCU for runs 15, 16, 17, and 18.

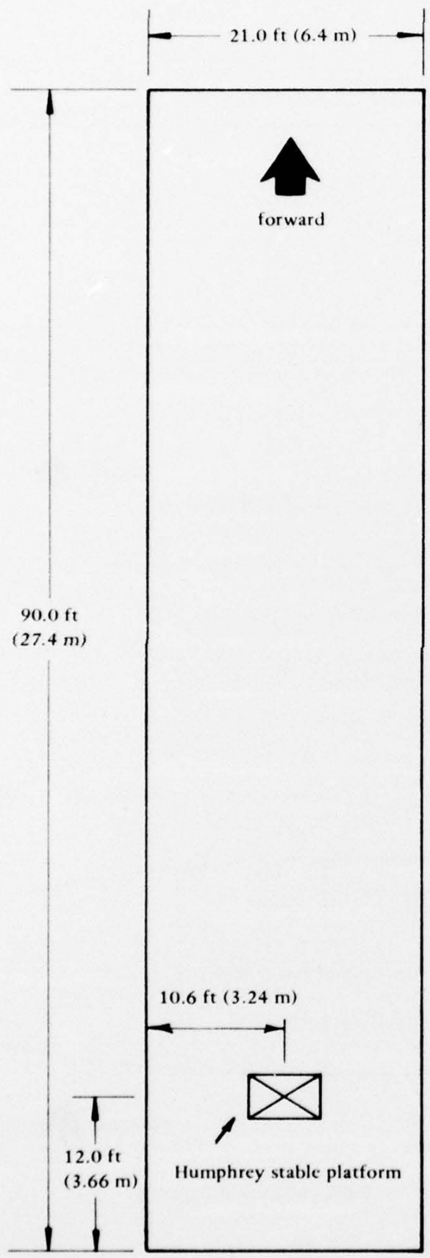


Figure 2-8. Humphrey stable platform location on midcauseway section for runs 19 and 20.

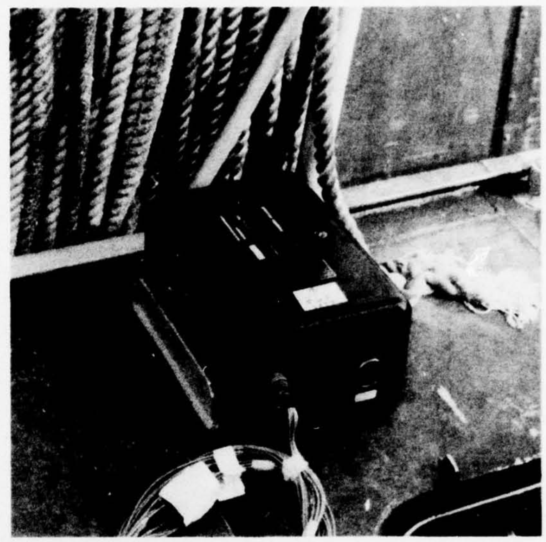
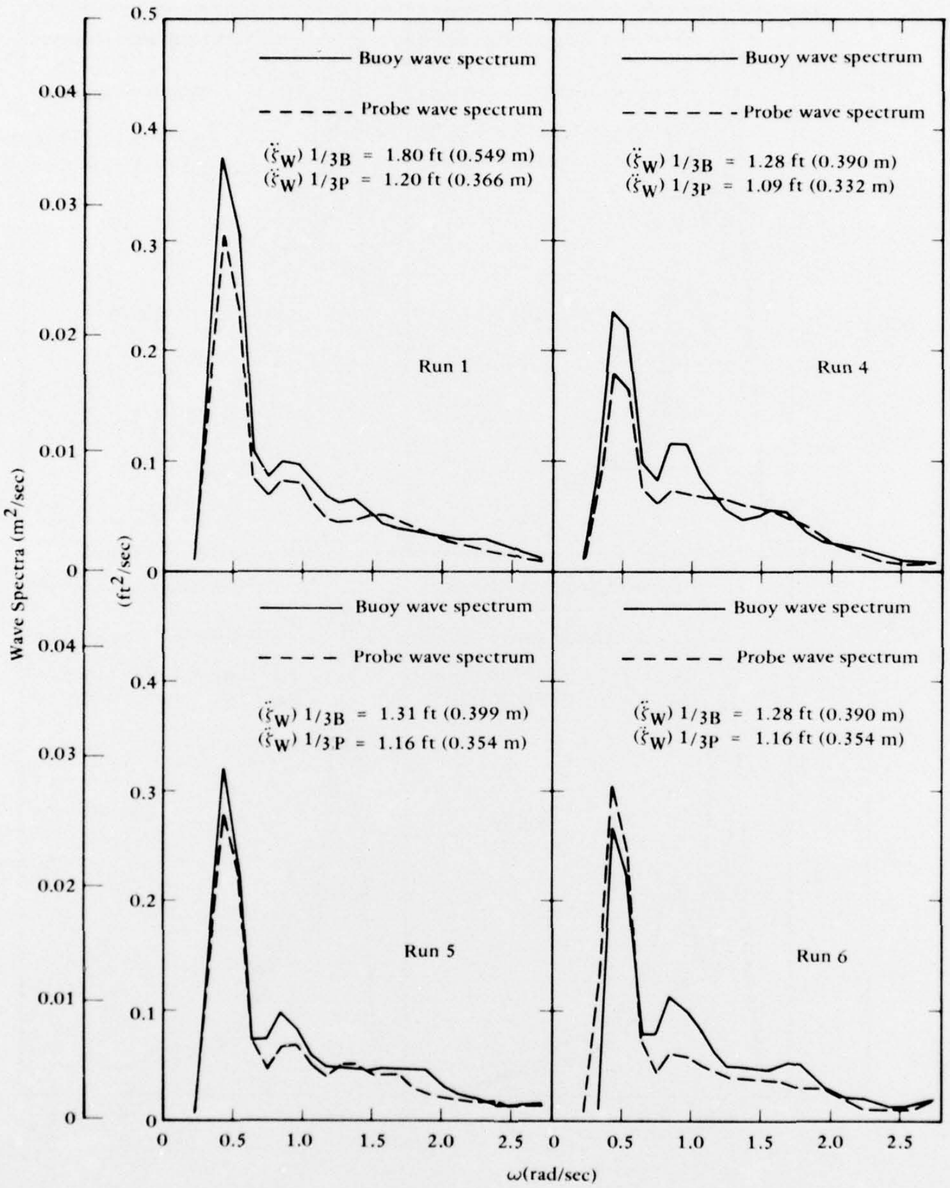


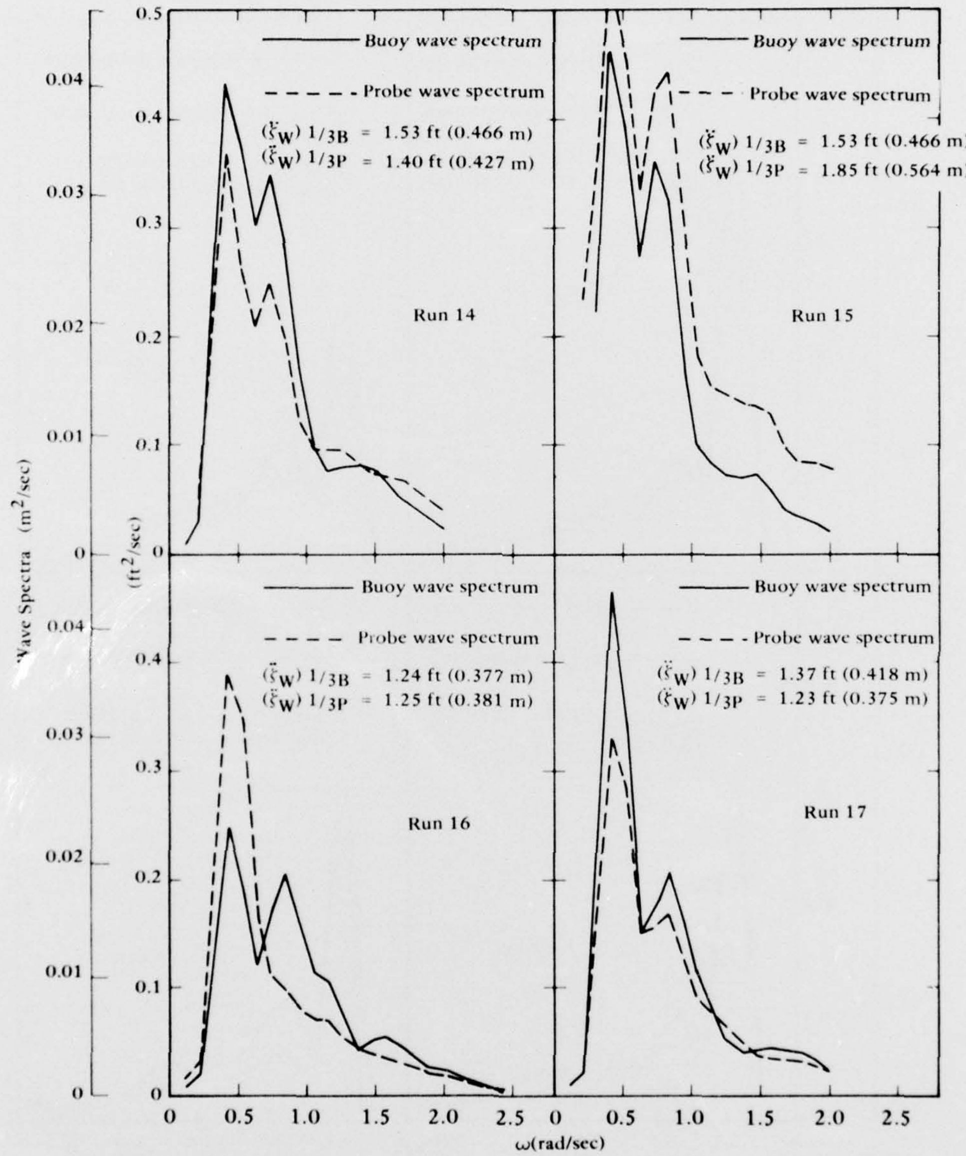
Figure 2-9. Humphrey stable platform mounted on LCM-8.

Figure 2-10. Wesmar ultrasonic probe fixed on end of elevated causeway.



*Based upon Figure 11 in DTNSRDC Report SPD-515-02: An investigation of the absolute lighter motions involved in the container off-loading and transfer system (COTS) trials.

Figure 2-11. Buoy and ultrasonic probe wave height spectra for runs 1, 4, 5, and 6.*



*Based on Figure 13 in DTNSRDC Report SPD-515-02: An investigation of the absolute lighter motions involved in the container off-loading and transfer system (COTS) trials.

Figure 2-12. Buoy and ultrasonic probe wave height spectra for runs 14, 15, 16, and 17.*

Table 2-1. Lighter Motion Test Condition[a]

Run No.[b]	Lighters Involved	Measurements	Operation	Date	Configuration
1	Tug and causeways	Waverider buoy wave height, ultrasonic probe wave height, pitch, roll, heave acceleration, surge acceleration, sway acceleration	Motion measurement of four empty containers being loaded onto causeway	2 Dec 75	Figure 2-4
4	Tug and causeways	Waverider buoy wave height, ultrasonic probe wave height, pitch, roll, heave acceleration, sway/sway acceleration	Motion measurement of four empty containers being loaded onto causeway	2 Dec 75	Figure 2-4
5	Tug and causeways	Waverider buoy wave height, ultrasonic probe wave height, pitch, roll, heave acceleration, surge acceleration, sway acceleration	Motion measurement of four empty containers being loaded onto causeway	2 Dec 75	Figure 2-4
6	–	Waverider buoy wave height and ultrasonic probe wave height	Waverider buoy wave height and ultrasonic probe wave height comparison	2 Dec 75	Figure 2-4
8	–	Waverider buoy wave height and ultrasonic probe wave height	Waverider buoy wave height and ultrasonic probe wave height comparison	3 Dec 75	Figure 2-5
9	1652 LCU, LCM-8	Waverider buoy wave height, ultrasonic probe wave height, pitch, roll, heave acceleration, surge acceleration, sway acceleration	Motion measurement of LCU loaded with two full containers alongside elevated causeway; LCM-8 rafted next to LCU	3 Dec 75	Figure 2-5
11	–	Waverider buoy wave height and ultrasonic probe wave height	Waverider buoy wave height and ultrasonic probe wave height comparison	3 Dec 75	Figure 2-6
13	–	Waverider buoy wave height and ultrasonic probe wave height	Waverider buoy wave height and ultrasonic probe wave height comparison	3 Dec 75	Figure 2-5
14	LCM-8	Waverider buoy wave height, ultrasonic probe wave height, pitch, roll, heave acceleration, surge acceleration, sway acceleration	Motion measurement of LCM-8 without containers alongside elevated causeway	4 Dec 75	Figure 2-6

continued

Table 2-1. continued

Run No.[b]	Lighters Involved	Measurements	Operation	Date	Configuration
15	1652 LCU	Waverider buoy wave height, ultrasonic probe wave height, pitch, roll, heave acceleration, surge acceleration, sway acceleration	Motion measurement of LCU without containers alongside elevated causeway	4 Dec 75	Figure 2-7
16	—	Waverider buoy wave height and ultrasonic probe wave height	Waverider buoy wave height and ultrasonic probe wave height comparison	4 Dec 75	Figure 2-7
17	1652 LCU	Waverider buoy wave height and ultrasonic probe wave height, roll, pitch, heave acceleration, surge acceleration, sway acceleration	Motion measurement of LCU without containers alongside elevated causeway	4 Dec 75	Figure 2-7
18	—	Waverider buoy wave height and ultrasonic probe wave height	Waverider buoy wave height and ultrasonic probe wave height comparison	5 Dec 75	Figure 2-7
19	Tug and causeways	Waverider buoy wave height, ultrasonic probe wave height, pitch, roll, heave acceleration, surge acceleration, sway acceleration	Motion measurement of tug and causeway loaded with eight empty containers	5 Dec 75	Figure 2-8
20	Tug and causeways	Waverider buoy wave height, ultrasonic probe wave height, pitch, roll, heave acceleration, surge acceleration, sway acceleration	Motion measurement of tug and causeway loaded with eight empty containers	5 Dec 75	Figure 2-8

[a]Based upon Table 1 in DTNSRDC Report SPD-515-02: An investigation of the absolute lighter motions involved in the container off-loading and transfer system (COTS) trials, by Lawrence C. Ruth.

[b]Runs 2, 3, 7, 10, and 12 deleted due to short run time.

Table 2-2. Significant Ship Motions[a]

Date	Run No.[b]	Run Start Time (DST)	Run Length (min)	Waverider Wave Height (ft, m)	Ultrasonic Probe Wave Height (ft, m)	Pitch (deg)	Roll (deg)	Heave Acceleration (g)	Surge Acceleration (g)	Sway Acceleration (g)	Heave Displacement (ft, m)
2 Dec 75	1	0959	44	1.30 (0.395)	1.20 (0.365)	1.38	0.441	0.018	0.021	0.012	1.07 (0.327)
	4	1302	33	1.28 (0.389)	1.09 (0.332)	1.24	0.433	0.016	0.020	0.008	0.857 (0.261)
	5	1356	23	1.31 (0.401)	1.16 (0.353)	1.36	0.450	0.016	0.020	0.009	0.984 (0.300)
	6	1450	30	1.28 (0.389)	1.16 (0.353)	–	–	–	–	–	–
3 Dec 75	8	1054	26	1.21 (0.368)	1.14 (0.346)	–	–	–	–	–	–
	9	1140	54	1.29 (0.392)	1.11 (0.337)	0.850	0.453	0.009	0.015	0.029	0.794 (0.242)
	11	1318	17	1.45 (0.442)	1.19 (0.363)	–	–	–	–	–	–
	13	1425	15	1.27 (0.386)	1.25 (0.382)	–	–	–	–	–	–
4 Dec 75	14	0735	29	1.53 (0.466)	1.40 (0.426)	2.38	0.740	0.036	0.019	0.040	1.09 (0.334)
	15	0833	31	1.53 (0.466)	1.85 (0.563)	1.50	0.640	0.013	0.019	0.072	0.569 (0.173)
	16	1128	7	1.24 (0.379)	1.25 (0.381)	–	–	–	–	–	–
	17	1139	30	1.37 (0.417)	1.23 (0.376)	1.28	0.523	0.010	0.017	0.078	–
5 Dec 75	18	0812	28	1.35 (0.411)	1.13 (0.344)	–	–	–	–	–	–
	19	0927	21	1.34 (0.410)	1.68 (0.511)	1.36	0.459	0.029	0.010	0.040	1.57 (0.479)
	20	0959	20	1.35 (0.413)	–	1.51	0.496	0.018	0.011	0.048	1.41 (0.429)

[a] Based upon Table 2 in DTNSRDC Report SPD-515-02: An investigation of the absolute lighter motions involved in the container off-loading and transfer system (COTS) trials, by Lawrence C. Ruth.

[b] Runs 2, 3, 7, 10, 12 deleted due to short run time. All significant values are double amplitude.

CHAPTER 3

ACKNOWLEDGMENTS

The following organizations provided direction, equipment, experience, and personnel necessary to achieve the excellent results of the advanced development tests. Without their cooperation and support the program could not have been accomplished:

Commander, Naval Surface Forces, Pacific, authorized the Amphibious Units to support the program.

Commander, Naval Beach Group, Amphibious Refresher Training Group, Coronado, approved and coordinated the beach support operations.

Amphibious Construction Battalion One provided the personnel and equipment to direct, install, and operate the elevated causeway.

Amphibious Assault Craft Unit One furnished the LCU landing craft and crews used to ferry the containers.

First Force Service Regiment, First Marine Division, Camp Pendleton, California, provided the drivers and truck/trailers used to move the containers on the causeway.

Naval Ship Research Development Center, Carderock, Maryland, conducted the motion measurements and analysis for the lighters moored to the pierhead.

Naval Electronics Laboratory Center, Human Factors Division, Code 3400, San Diego, provided the human engineering study of the elevated causeway system.

Public Works Center, U. S. Naval Station, San Diego, fabricated the spudwells, installed and load-tested the external spudwells, and provided welders durint the operation.

Construction Equipment Department and Marine Terminal Division, NCBC, Port Hueneme, assembled all of the pierhead pontoon sections.

Transportation Division, NCBC, Port Hueneme, provided operators and a construction crane for both the Phase I and Phase II tests.

CEL Support Operations Department; Logistics Support Division; Planning Branch; and Technical Support Branch.

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COMCBPAC Operations Off, Makalapa HI
COMNAVMARIANAS Code N4, Guam; FCE, Guam
COMSUBDEVGRUONE Operations Offr, San Diego, CA
DEFENSE DOCUMENTATION CTR Alexandria, VA
DNA STTL, Washington DC
MARINE CORPS BASE PWO, Camp S. D. Butler, Kawasaki Japan
MARINE CORPS DIST 9, Code 043, Overland Park KS
MCAS Code PWE, Kaneohe Bay HI; PWO
MILITARY SEALIFT COMMAND Washington DC
NAS Code 18700, Brunswick ME
NATL RESEARCH COUNCIL Naval Studies Board, Washington DC
NAVAL FACILITY PWO, Centerville Bch, Ferndale CA
NAVCOASTSYSLAB CO, Panama City FL; Code 710.5 (J. Quirk); Library
NAVEODFAC Code 605, Indian Head MD
NAVFACENGCOM Code 0433B; Code 0451; Code 0453 (D. Potter); Code 04B5; Code 101; Code 104; Code 2014 (Mr. Taam), Pearl Harbor HI; PC-22 (E. Spencer); PL-2
NAVFACENGCOM - CHES DIV. Code FPO-1 (Ottsen)
NAVFACENGCOM - LANT DIV. RDT&ELO 09P2, Norfolk VA
NAVFACENGCOM - NORTH DIV. Code 1028, RDT&ELO, Philadelphia PA
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NAVFACENGCOM - WEST DIV. Codes 09PA; O9P/20
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NCBC CEL (CAPT N. W. Petersen), Port Hueneme, CA; CEL AOIC; Code 10
NCR 20, Commander
NMCB 5, Operations Dept.; 74, CO; One, LT F.P. Digeorge
NROTCU Univ Colorado (LT D R Burns), Boulder CO
NTC Code 54 (ENS P. G. Jackel), Orlando FL; OICC, CBU-401, Great Lakes IL
OCEANAV Mangmt Info Div., Arlington VA
ONR CDR Harlett, Boston MA; Dr. A. Laufer, Pasadena CA
PMTC Pat. Counsel, Point Mugu CA

PWC Code 116 (ENS A. Eckhart); ENS J.A. Squatrito, San Francisco Bay, Oakland CA; OIC CBU-405, San Diego CA
USCG R&D CENTER D. Motherway, Groton CT; Tech. Dir.
USNA Ch. Mech. Engr. Dept; Sys. Engr Dept (Dr. Monney), Annapolis MD
CALIFORNIA INSTITUTE OF TECHNOLOGY Pasadena CA (Keck Ref. Rm)
FLORIDA ATLANTIC UNIVERSITY BOCA RATON, FL (MC ALLISTER)
IOWA STATE UNIVERSITY Ames IA (CE Dept, Handy)
LEHIGH UNIVERSITY Bethlehem PA (Linderman Lib. No.30, Flecksteiner)
LIBRARY OF CONGRESS WASHINGTON, DC (SCIENCES & TECH DIV)
MASSACHUSETTS INST. OF TECHNOLOGY Cambridge MA (Rm 10-500, Tech. Reports, Engr. Lib.); Cambridge MA (Rm 14 E210, Tech. Report Lib.)
MICHIGAN TECHNOLOGICAL UNIVERSITY HOUGHTON, MI (HAAS)
PUa DUE UNIVERSITY LAFAYETTE, IN (ALTSCHAEFFL)
TEXAS A&M UNIVERSITY COLLEGE STATION, TX (CE DEPT); College TX (CE Dept, Herbich)
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UNIVERSITY OF DELAWARE Newark, DE (Dept of Civil Engineering, Chesson)
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BECHTEL CORP. SAN FRANCISCO, CA (PHELPS)
BELGIUM NAECON, N.V., GEN.
CANADA Mem Univ Newfoundland (Chari), St Johns; Surveyor, Nenninger & Chenevert Inc.,
DILINGHAM PRECAST F. McHale, Honolulu HI
DRAVO CORP Pittsburgh PA (Giannino)
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NORWAY J. Creed, Ski; Norwegian Tech Univ (Brandtzaeg), Trondheim
PACIFIC MARINE TECHNOLOGY LONG BEACH, CA (WAGNER)
PORTLAND CEMENT ASSOC. SKOKIE, IL (CORELY); Skokie IL (Rsch & Dev Lab, Lib.)
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UNITED KINGDOM Cement & Concrete Assoc. (Lit. Ex), Bucks; Cement & Concrete Assoc. (R. Rowe), Wexham Springs, Slough B; D. New, G. Maunsell & Partners, London; Taylor, Woodrow Constr (014P), Southall, Middlesex
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ARMY MAT SYS ANALYSIS ACT Code DRXSY-CM (M Ogorzalek) Aberdeen Proving Grnd MD
ARMY MOBIL EQUIP R&D COM Code DRXFS-MR Fort Belvoir, VA; F. Stora Fort Belvoir, VA
ARMY MTMC Trans Engr Agency (D.E. Eichhorn) Newport News, VA
ARMY TRANSPORTATION SCHOOL V Quingy Code ATSP-CPD-MS Fort Eustis, VA; V. Quingy Code ATSP-CPD-MS Fort Eustis, VA
ARMY TRNG & DOCTRINE CMD Code A7CD-SP-L Fort Monroe, VA
CNM Code 03462 Washington DC; Code 043 Washington DC
CNO Code OP 405, Wasington DC; Code OP 414 Washington DC; Code OP 97 Walshinton DC; Code OP 987 Washinton DC; Code OP323 Washington DC
COMNAVBEACHPHIBREFTRAGRU One San Diego San Diego CA
DEPCOMOPTEVFORPAC Code 701A, San Diego, CA
DTNSRDC Anna Lab (Code 1175) Annapolis MD
EMFPAC CG
MARCORPS First Service Support Group Camp Pendleton, CA
MCDEC P&S Div Qyantico, VA

NAVFACENGCOM Code 043 Alexandria, VA; Code 044 Alexandria, VA; Code 04B3 Alexandria, VA; Code 04B5 Alexandria, VA
NAVPHIBASE CO, ACB 2 Norfolk, VA; Dir. Amphib. Warfare Brd Staff, Norfolk, VA
NAVCHAPGRU CO Williamsburg, VA
NAVCOASTSYSLAB Code 772 (C.B. Koesy) Panama City, FL
NAVFACENGCOM Code 06, Alexandria VA
NAVOCEANSYSCEN Code 3400 San Diego, CA
NAVPHIBASE CO ACB One San Diego CA; COMNAVBEACHGRO Two Norfolk, VA
NAVSURFLANT Norfolk VA
NCBC Code 155, Port Hueneme CA
NCR FWD 30th CDR Diego Garcia Island
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